

**CORDILLERA REAL
GEOLOGICAL RESEARCH PROJECT**

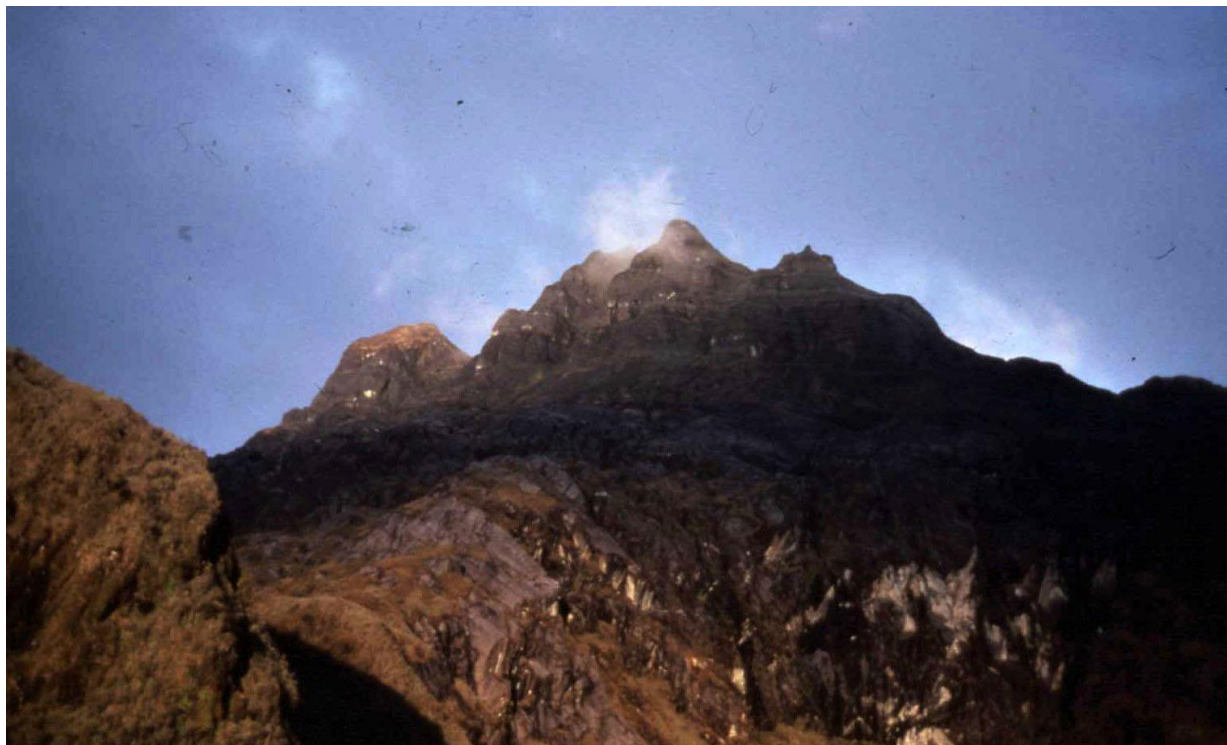
**SECOND ANNUAL REPORT
(APRIL 1987 – MARCH 1988)**



British Geological Survey

**Keyworth
Nottinghamshire**

PATRI MATRIQUE



Sunrise at Cerro Hermoso in the Llanganates

Inca treasure

Llanganates, the mountains of the mind,
Where cold mists and rain leave you undefined,
You're straddled by Cerro Hermoso's sweep,
Atahualpa's treasure is yours to keep.

Rumiñahui, loyal lieutenant he,
When advised of Pizarro's treachery,
Manoeuvred his gold-laden llama train
To this twisted, ice-worn, rocky terrain.

Valverde was first to the treasure site.
In a cave or a lake? Which one is right?
Wrote his derrotero before he died:
It's always been an ambiguous guide.

After three days of walking, cold and wet,
We reach two mighty tents in silhouette.
Standing outside: "Have you a drink for me?"
"Vee see you soon, Vee are having our tea."

Bankers from Stockholm with tons of supplies;
So the next morning I sent out my spies:
Charting the lake with sonar equipment:
Trying to find Rumiñahui's shipment.

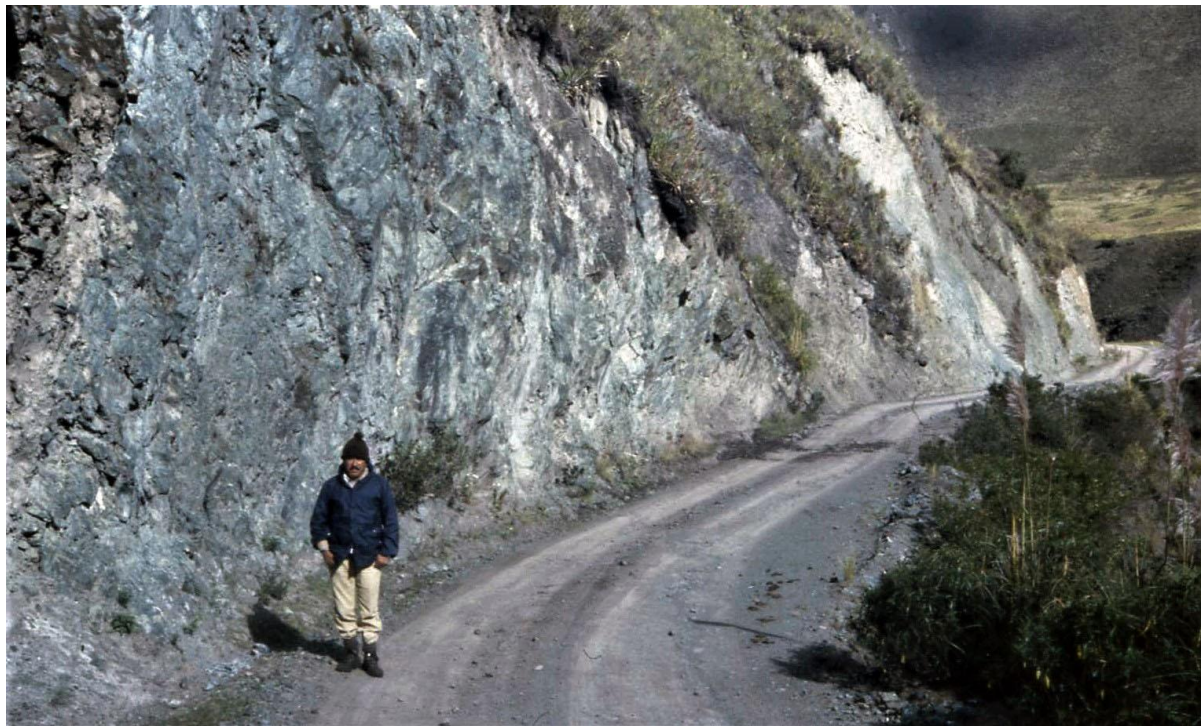
We climbed Hermoso; we mapped all the rocks.
We noticed the potholes that drained the lochs.
We followed the black marbles all around,
In which potholes and caves were underground.

Our final morning, approaching the Swedes:
"We know what you're doing! Hope it succeeds!
But surveying the lake may be in vain.
When our map's published, you should come again!"

Martin Litherland
Inca Treasure
Poems from the Andes of Ecuador



Sheared carbonate band, N of Baños, Rio Pastaza, Baños - Puyo Traverse



Greenstones from the Peltetec division

Overseas Development Administration,
Foreign and Commonwealth Office,
United Kingdom of Great Britain
and Northern Ireland

Ministerio de Energía y Minas,
República del Ecuador

CORDILLERA REAL
GEOLOGICAL RESEARCH PROJECT

SECOND ANNUAL REPORT
(ABRIL 1987 – MARZO 1988)

compiled by

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ABSTRACT

This report accounts for the work undertaken from April 1987 to March 1988 under the Cordillera Real Geological Research Project: a bilateral (ODA-INEMIN) Technical Cooperation programme. It includes and summarises the results of geological field work, laboratory analyses, and heavy mineral, petrographic, fluid inclusion and geochronological Rb-Sr studies undertaken during this period.

Geological fieldwork has concentrated on three sectors of the Cordillera Real metamorphic complex: the western (collision) belt between Riobamba-Penipe and Cuenca-Paute; the metamorphic complex between the Papallacta and Pastaza rivers; and the metamorphic complex between the Rio Paute and the Peruvian border. Geological maps on a scale of 1:250000 are included for these three sectors along with the 1:50000 geotraverse maps.

Over the Western belt, of probable Mesozoic age, the Andean-trending lithological divisions of the metamorphic complex identified in the first Annual Report have been mapped along strike. In the west the Guasuntos, Guamote and Cebadas divisions are continental-derived sediments thrust westwards at low angles over a presumed Chaucha-Arenillas continental plate. These are bordered eastwards, along the Peltetec fault, by a steeply-dipping ophiolitic mélange, the Peltetec division, followed further east by forearc sediments and andesites (Maguazo division) and island arc andesites and sediments (Alao-Paute division) as far as the Baños front. The Peltetec fault, and other “collision” faults, are manifested as Cenozoic structures due to later rejuvenation.

Over the Central and Eastern belts, east of the Baños front, there have been extensive studies between the Papallacta and Pastaza rivers and between the Rio Paute and the Peruvian border. Along the Central belt the oldest rocks belong to the Sabanilla basement complex of probable Precambrian age. Younger Phanerozoic metasediments occur in the south in the form of the Loja phyllitic semi-pelite division, whilst, further north, these pass into higher-grade schists and paragneisses with a metavolcanic component. There are indications that some of these rocks can be traced into volcano-sedimentary sequences of the sub-Andean Eastern belt, cut by the sub-Andean plutonic division (Zamora-Abitagua) dated by Rb-Sr as Upper Triassic to Mid-Jurassic in age. Within the Central belt, immediately east of the Baños front, a chain of S-type (collision) metagranites has been mapped, the Tres Lagunas suite, which in many places show blue quartz grains and smoky K-feldspar megacrysts.

The structure of the Central belt is manifested in the north by large-scale thrust sheets involving, primarily, ophiolitic and skarn rocks, and granites of the Tres Lagunas suite. The eastern carbonate sequence of Cerro Hermoso is not involved in this thrusting. It is possible that the thrusts belt represents eastward transport away from the Peltetec (collision) suture. Further south, flat foliation belts have also been recorded. The structure of the Eastern belt is complicated by the tectonic overprint of Tertiary high-angled thrust involving Cretaceous Formations of the Oriente.

With regard to the mineral potential of the Cordillera Real, new mineral indications have been noted and the following mineral belts can be proposed:

- (a) **The Peltetec ophiolitic belt:** there are indications/reports of Au, Ag, Ni, Cu, Zn, Mn and Cr mineralization.
- (b) **The Tampanchi mafic igneous complex:** is a dominantly clinopyroxenite/hornblendite body within the Alao-Paute division with evidence of cumulate textures. It may be the first layered mafic igneous complex recognised in Ecuador. Its identification has precipitated mining company interest who report the presence of Au and Pt. Prospection should be undertaken for Bushveld-type minerals.
- (c) **The Altar-San Bartolomé polymetallic belt:** is of known and new Cu-Zn-Pb-Ag occurrences underlain by the Alao-Paute (metavolcanic) division, with mineralization within the metamorphic rocks or Cenozoic volcanic/subvolcanic units along reactivated collision faults.
- (d) **The Collay-Shincata gold belt:** is based on known and new alluvial occurrences. The gold sources are thought to be structurally related to the Baños front mylonite belt (7 km wide) and/or its structural control on Cenozoic volcanic/subvolcanic activity.
- (e) **The Tres Lagunas tin-tungsten belt:** there is the probability of Sn-W mineralization related to Tres Lagunas S-type collision granite suite at Saraguro and Peggy Mine. Since this unit extends all along the Cordillera Real there is thus the possibility of a “Malaya-type” belt of tin granites in Ecuador.
- (f) **The Llanganates skarn/ophiolite belt:** a new skarn field (El Placer) has been identified in the Llanganates, and further north there are ophiolite/skarn occurrences. All indications are that these rocks are in the form of thrust sheets. Gold results from the El Placer skarn field are poor, and the metalliferous potential of this region requires further studies.
- (g) **The sub-Andean gold belt:** is known from hard rock (e.g. Nambija) and placer deposits. Studies show that this belt is spatially and probably metallogenetically related to the sub-Andean volcano-plutonic division, a belt of plutons and associated subvolcanic and volcanic rocks which trends from Zamora to the Abitagua granite.

Outside the Cordillera Real, a field trip to El Oro Province discovered a new 5 km-wide ophiolite belt at Rio Palenque south of Pasaje. Later mining company activity reports gold-bearing rivers.

1. INTRODUCTION

1.1 Nature of this report

This is the second of a series of open file annual reports on the Cordillera Real Geological Research Project: a bilateral Technical Cooperation project between the Governments of Ecuador (Instituto Ecuatoriano de Minería-INEMIN: Ministry of Energy and Mines) and the Government of the United Kingdom of Great Britain and Northern Ireland (Overseas Development Administration-ODA), which began in March, 1986. The Technical Cooperation officers are recruited from the British Geological Survey (BGS). The present report covers the period April 1987-March 1988.

The Project aims to study the metamorphic rocks of the Cordillera Real of Ecuador. Its objectives are the elucidation of their nature, structure, relationship and mineralization in order to discover the patterns of metallogenesis and provide the scientific base for estimating their mineral potential, and thus a database to promote the Ecuadorian Mining Industry.

For details of background, personnel, topography, drainage, climate, vegetation, population, access, topographic maps, imagery, previous geological work and mining history, the reader is referred to the first annual report (Litherland, 1987).

1.2 The April 1987 – March 1988 work programme

The first annual report described the results of a number of geotraverses across the Cordillera Real using the methodology described in Litherland (1987) for the collection of scientific data. These geotraverses indicated certain geological units, such as the division of the metamorphic rocks of the Cordillera Real into the Western, Central and Eastern (geo-tectonic) belts. Mineral occurrences were tentatively related to geological processes within a specific belt. In the light of these preliminary discoveries the following work programme (Fig. 1) was planned and accomplished over the Cordillera Real utilising the same methodology. In addition, a major geochronological sample collection programme was undertaken, and a reconnaissance trip was made to the El Oro metamorphic province. Office and laboratory work under and outside the *convenio* are also accounted for.

1.2.1 The Western belt between Riobamba-Penipe and Cuenca-Paute

This sector (Map 1) was investigated by Litherland and Bermúdez in July-August 1987. Lithological divisions noted in Litherland (1987) and related to collision tectonics were traced throughout the belt (Map 1). The region is relatively easy for vehicle-access and it is thought that sufficient reconnaissance studies have now been carried out over this area by the Project to provide a degree of geological understanding defined in the Project aims.

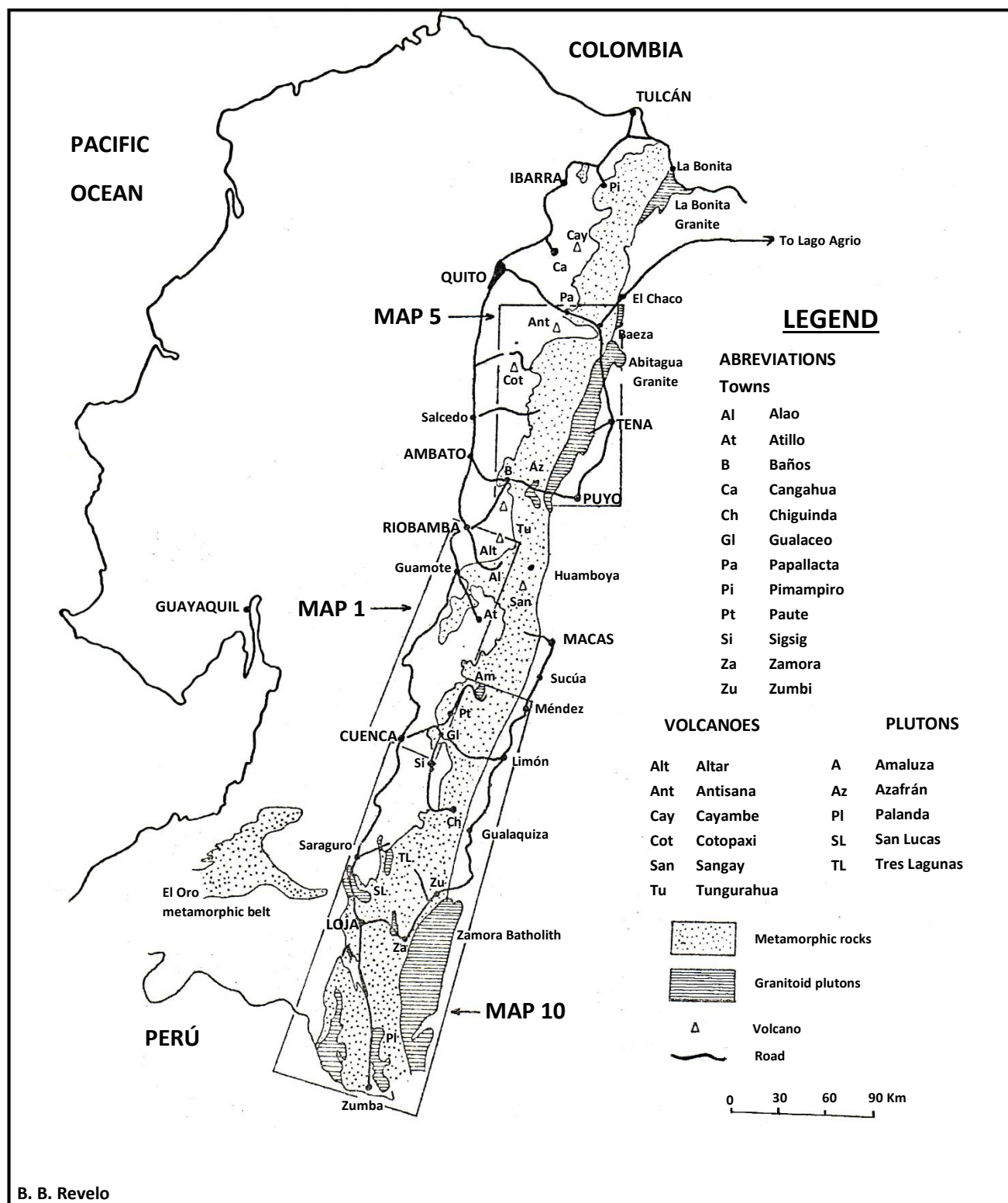


Figure 1. 1987-1988 Project work areas indicating relevant 1:250000 scale regional maps. Geology after Baldock (1982).

1.2.2 The Central Belt between the Papallacta and Pastaza rivers

This sector of the complex Central belt (Map 5) was traversed three times during the first year's studies: along the Papallacta-Baeza road (Río Papallacta), along the Baños-Puyo road (Río Pastaza) and down the Río Mulatos. The area is extremely difficult of access and trips are invariably accompanied by bad weather. It was decided to study this particular area in more detail for two reasons: (a) the Río Mulatos geotraverse encountered skarn and serpentinite blocks of economic and geological interest; and (b) further geotraverses north of the Río Papallacta could not be seriously considered on account of severe damage along the Subandean zone caused by the March 5th 1987 earthquake.

Thus, between October 1987 and January 1988 Litherland and Bermúdez undertook three foot traverses: (a) a reconnaissance geotraverse east of the Río Antisana (south of Antisana volcano); (b) a follow-up traverse to find the source of the Río Mulatos skarn blocks; and (c) a reconnaissance geotraverse from El Triunfo to Cerro Hermoso, the highest peak of the Llanganates.

In addition to these traverses, Dr. Litherland accompanied a helicopter trip to the Río Chalupas, sponsored by BP Minerals International.

These four field excursions have provided much new information at approximately 20 km spacings between the Papallacta and Pastaza rivers (110 km), providing insight into exiting new geological and mineral possibilities. Further project studies are required over this area to establish a definitive picture.

1.2.3 The Central and Eastern belts between the Río Paute and the peruvian border

In the first year this sector was traversed from Paute to Méndez (Río Paute), and along the Cuenca-Limón, Loja-Zamora and Loja-Zumba roads. Further wide-ranging traverses were planned and accomplished during the period in question in order to more fully understand the complex Central belt geology and mineral potential of this sector of known gold mineralization (Map 10). Thus, between August 1987 and February 1988 Aspden and Viteri undertook the following geotraverses: Oña - 28 de Mayo; Sigsig Río Santa Bárbara; Gima - Chigüinda - Gualaquiza; Sevilla de Oro - Copal; Chorro Blanco - Collay; Santa Rosa - Chorro Blanco; Collay - Quebrada Esmeraldas; Santa Teresita - Río Arenillas; Laguna Maylas - Río Pilares - La Merced; Zumba - Río San Francisco; Valladolid-Porvenir; Loja - San Lucas; and studies around the margin of the Malacalá basin. These studies were carried out along roads and horsetrails and over areas with no communications.

These studies have provided a database for the understanding of the geology and mineral potential of this sector.

1.2.4 The first Project geochronological programme

During May and June, 1987, Dr. C. C. Rundle (of the then Isotope Geology Unit, British Geological Survey), accompanied by Dr. Aspden and Ing. Bermúdez or Ing. Viteri, were engaged in a wide-ranging geochronological sampling programme of the Cordillera Real, in particular the plutonic and meta-plutonic units. The programme was carried out along roads or vehicle tracks utilising dynamite where fresh samples were unobtainable by hammering. The samples were crushed and separated in the INEMIN laboratories (Chillogallo). 130 rock samples (about 1000 kg) were collected for analysis by the Rb-Sr method (98 samples), the K-Ar method (74 samples) and the Sm-Nd method (8 samples). This represented the first major systematic geochronological programme to utilize the Rb-Sr method in Ecuador.

Details of the sampling programme and the geochronological results are given in Appendix 3.

1.2.5 Reconnaissance geological excursion to El Oro Province

This was undertaken in order to examine the metamorphic rocks of this province so that the Project team could have an overview of all the exposed metamorphic rocks of Ecuador. Of particular importance is the regional interpretation touched on in Litherland (1987), involving the relationship of the two metamorphic provinces (El Oro and Cordillera Real) in the interpretation of the regional Huancabamba Deflection. Details of the geology and local and regional interpretations are given in Appendices 8 and 9.

1.2.6 Petrographic studies

Thanks to the installation of rock-cutting facilities in the INEMIN laboratory (by the West German Government) the project now has over 500 microscopic thin sections of rocks collected over the Cordillera Real during the two years of the project. These have been a considerable aid in the petrographic identification of lithotypes.

BP Minerals International sponsored the petrographic study of skarn rocks from the Río Mulatos follow-up area (Appendix 5).

BP Petroleum (Quito) sponsored the petrographic analysis of certain samples of the Tres Lagunas granitoid belt (Appendix 6).

1.2.7 Chemical analysis

The routine element analysis of stream sediments and rocks has been disrupted by a major reconstruction programme of the INEMIN (Chillo Gallo) laboratories. Results available are listed in Appendices 1 and 2.

BP Minerals International sponsored the analysis of the Río Mulatos skarn rocks (Appendix 1).

1.2.8 Heavy mineral analysis

BP Mineral International sponsored the study of the heavy minerals collected from the first year's Río Mulatos geotraverse (Appendix 4). It is hoped that the Project can begin working on the remainder of the heavy mineral samples in the near future.

1.2.9 Fluid inclusion studies

BGS studies on Nambija skarn samples are included as Appendix 7.

1.2.10 Commission reports and maps

Reports and maps compiled for INEMIN following field commissions (field excursions) are presented in Appendix 10. It must be emphasised that the bulk of these reports are based on field data only, without the aid of microscopic petrographic studies.

1.2.11 Publications

Regional plate/terrane interpretations of Ecuadorian geology appear in Aspden et al. (1987) and Aspden and Litherland (1987) (Strasbourg EUG IV Abstract). These interpretations are superseded by Aspden et al. (in press), a copy of which is included as Appendix 8.

1.3 Report and map presentation

Again, this annual report attempts to include all the data obtained by the Project in the period in question so as to be of maximum benefit to interested parties. The first part of the report is produced in Spanish and English versions. However, with the exceptions of Appendix 8, the remainder of the Appendices are reproduced in their language of presentation.

The description of the geology has been made with the benefit of information from microscopic thin sections. It therefore supercedes descriptions presented in the field reports (Appendix 10).

The maps are presented in an ordered sequence covering the three areas of study. Maps for a particular area begin with the 1:250000 coloured compilation followed by geotraverse/sample maps at larger scales covering sectors of the same area. The 1:250000 scale compilations are constructed on a topographic base prepared by the Project from existing surveyed IGM sheets and LANDSAT information over other sectors.

1.4 Acknowledgements

We are again indebted for financial and administrative support to INEMIN through the ex-Gerente General, Sr. Horacio Rueda J., and subsequently, Ing. Guillermo Bixby G.; and to ODA through both the Latin America Desk Officer, Mr. G. Roberts, and Mr. R. Norton, Aid Officer, British Embassy, Quito. Despite financial constraints on both parties to the *convenio*, their respective institutions have managed to maintain the progress of the Project.

We also appreciate the scientific support provided by Ing. E. Salazar (Gerente Técnico of INEMIN) and Dr. C. R. Jones (BGS Regional Geologist, Latin America and Asia) who monitors the Project for ODA. Both Ing. Salazar and Dr. Jones have followed the progress of the Project with interest and we hope that this report meets their standards and expectations. Another who follows the Project is Econ. Manuel Horra, Deputy Minister (Mines), and we appreciate his keen interest in the collision models and other exiting theories for regional mineral potential. Last, but not least, the project has benefited this year from the stalwart services of Manuel Céleri, INEMIN field assistant, whose role in the success of Project field excursion over difficult terrains cannot be exaggerated.

With so many constraints on government budgets, it is a pleasure to note the contribution made by BP Minerals International and BP Petroleum Quito to this report which is freely available to the public.

The Project now knows a lot more about the geology of Cordillera Real of Ecuador than any other institution and has become a data pool of particular use to the Mining Companies. We operate on a “give and take” basis, all in the interests of promoting the Ecuadorian Mining industry: the real motivation for the ODA-INEMIN *convenio*.

2. GEOLOGY

2.1 Introduction

The following gross tripartite division of the Cordillera Real metamorphic complex is maintained from Litherland (1987) for ease of description:

- (a) The Western belt: limited to the east by the Baños front.
- (b) The Central belt: limited to the west by the Baños front and to the east by the Sub-Andean front.
- (c) The Eastern belt: limited to the west by the Sub-Andean front and to the east by the unmetamorphosed/uncleaved rocks of the Oriente.

The Central belt rocks are still an enigma in terms of age, stratigraphic relationships and structural setting, although much more data is now available and a number of reasoned hypotheses can be proposed. In contrast, the Sub-Andean front marks the western limit of recognition of the diagnostic Cretaceous formation of the Oriente; whilst the Baños front marks the eastern limit of recognition of a sequence of well-defined lithological divisions within the Western belt. Sufficient data has now been obtained to indicate that the apparent difficulties of interpretation over the Central belt do not relate to the greater degree of inaccessibility over the eastern Andean slope, but are in fact a geological reality. Thus, the Western and Eastern belts are both easier of access and interpretation, leaving the Central belt as the main challenge for the remainder of the project.

2.2 The Western Belt

2.2.1 Introduction

As previously stated, the rocks of the Western belt of the Cordillera Real metamorphic complex form a well-defined series of lithological divisions of low metamorphic grade bounded to the east by the Baños front. Outcrops are mainly restricted to area of Map 1, i.e. between Riobamba-Penipe in the north and Cuenca-Paute in the south. Many of these outcrops are in the form of basement inliers under Cretaceous-Cenozoic units. Further north and south these cover units completely bury the Western belt basement. However, in the extreme north of the country, within the Inter-Andean graben, there are further 'inliers' in the sector around Ambuquí (Litherland, 1987).

As stated by Litherland (1987) rocks of the Western belt include rocks previously allotted to the Paute Group and parts of the previous Ambuquí, Llanganates and Zamora Groups of Baldock (1982).

This section describes the Western belt of the main outcrop area. The preliminary work (Litherland, 1987) identified certain lithological divisions eastwards from Guamote to the Alao Valley. These divisions have been traced north and south. New divisions have been identified and a previous one amended (Table 1): a permissible practice since the units are informal.

Table 1. Divisions of the Western Belt from West (Top) to East (Bottom)

Litherland (1987)	This report
	Guasuntos black slate division
Guamote quartzite division	Guamote quartzite division
Cebadas black phyllite division	Cebadas black slate division
	Peltetec mélange division
Peltetec subduction complex	Maguazo turbidite and greenstone division
Alao-Paute greenstone and metasedimentary division	Alao-Paute greenstone and metasedimentary division
	Tampanchi mafic igneous complex (Guarumales division)

2.2.2 Lithologies of the Guasuntos, Guamote and Cebadas division

These three divisions can be grouped together since they exhibit a common sedimentary affiliation and tectonic style. The “group” is bounded by two newly-identified faults: in the east the Peltetec fault and in the west the Ingapirca fault, the latter showing downthrow to the west (basement against cover). River blocks of Guamote-type quartzite were noted in Quebrada Bashog, 1.5 km S of Yaruquíes and west of the Ingapirca fault, but they may be derived from conglomerate.

Outcrops extend from the Punín inlier in the north to the Río San Pedro, east of Cañar, in the south, a distance of ca 100 km. On the Cañar geological sheet (Bristow et al., 1975) the Guamote division includes the “Ingapirca Formation” interpreted by Bristow et al. (1975) as part of the Yunguilla (Maastrichtian) cover sequence.

The Guasuntos and Cebadas divisions comprise black or grey slates with subordinate black or grey fine to medium-grained quartzite beds. In the Guamote division quartzites predominate over the pelitic beds.

The Guamote division exhibits lithological changes from north to south. In the Punín inlier and Guamote sector the quartzites are pale to medium grey, pink or red in colour and vary from medium-grained feldspathic types through coarse-grained types to conglomerates with clasts up to 1 cm across. These are intercalated with black, grey, purple, green or pale pelitic slates which, in the quarry 200 m E of Punín, are essentially unmetamorphosed. There are also banded fine ferruginous sandstones. Clay-concretions, ferruginous in places, and up to 20 cm across, were noted in the quartzites, and smaller examples in the black mudstones near Punín.

The coarse-grained quartzites show subrounded to angular clasts dominated by milky quartz, with subordinate clasts of smoky quartz, mudstone pellets, and pyrite-rich, fine-grained recrystallised acid volcanoclasts, in a matrix of more-rounded fine quartz.

Further south, around Palmira, the conglomerates remain pale grey but the quartzites are grey or black due to the presence of smoky quartz clasts. Clasts of blue quartz were also noted. The pelitic fraction is grey to black, without the pale, green and purple intercalations of the northern outcrops.

Further south along the Ríos Zula, Silante and San Pedro the Guamote division is entirely grey to black in colour. The quartzites are fine to medium-grained, poorly sorted, and dominated by smoky quartz clasts with subordinate blue quartz.

The tectonic history of the group has evidently destroyed sedimentary structures which could indicate 'way-up' and provenance. However, the group is interpreted as a continental-derived sequence with the northern outcrops of the Guamote division of shallower-water type nearer to the shoreline.

2.2.3 Tectonics of the Guasuntos, Guamote and Cebadas divisions

The characteristic tectonic feature of this group is the flatness of tectonic structures manifested as cleavages and sheared fold limbs; this is in marked contrast to the structure east of the Peltetec fault.

In the north, a gently-dipping, penetrative first cleavage can be identified usually sub-parallel to bedding, especially in the pelitic units; although in the quarry mudstones 200 m east of Punín it is barely discernable. South of Palmira this is cut by a gently-dipping second crenulation cleavage roughly parallel with the first. Over the entire area there are 70 deg-trending, late, upright, open-to-close folds associated in places with a subvertical crenulation cleavage. Thus, steep dips of bedding/S₁/S₂ may be encountered. These late structures are not found in the 'steep belt' east of the Peltetec fault and are believed to relate to a younger post-"Macuchi" event.

Both the S₁ and S₂ cleavages are axial planar to minor folds many of which show overall tectonic transport to the west (i.e. they are of "Z" form looking south and "S" form looking north). At river outcrops 200 m east of Punín small 'ramp' structures in quartzites also indicate westward transport.

Along the Pan-American highway just south of Guamote, there are tectonic lenses of quartzite within slates indicating E-W stretching along the first cleavage. The intermediate axis of these ellipses measures up to 20 m. All this evidence, combined with the fact that with the most common dip is gently eastward, indicates a thrust belt with westward tectonic transport.

2.2.4 The Peltetec division

This unit was first recognised near Peltetec (Alao Valley) and in the adjacent Huarguallá Valley to the south as an ophiolitic complex (Litherland, 1987). The present report narrows the unit down to a 1-2 km wide zone of tectonic mélange, with or without ophiolite, which can be traced from Penipe in the north to the Río Zula in the south (Map 1), a distance of about 85 km. Map 1 shows a possible northward extension to include metabasalts of the Río Blanco de Patate (Ing. E. Salazar, personal communication).

The following lithologies were noted on the traversed sections:

- (a) **Penipe:** black antigoritic serpentinites with carbonate veins crop out along the main track (Map 2) along with fresh hornblendites and black phyllites. The dominant lithology is a fine-grained, strongly cleaved, green metalava probably corresponding to a metabasalt.
- (b) **Alao (Peltetec):** cherts and black phyllites are followed east by the main stream section (Map 3) where float blocks indicate black serpentinites and a variety of undeformed medium to coarse-grained magmatic rocks with fresh clinopyroxene and altered plagioclase, sometimes with altered olivine. They include coarse gabbros, olivine gabbros, metagabbros and picrites. There are also leucogabbros with fresh plagioclase and altered pyroxene. Some of these rocks exhibit ophitic textures, others possible cumulate textures. There are also blocks of a coarse periclase-brucite-?idocrase rock.

Exploring up the stream gully, outcrops of serpentinite were encountered, and higher up there is an outcrop containing dolerite and gabbro with a vertical contact.

The remainder of the road section comprise mainly fine-grained, massive, vesicular, spillitic basalts and breccias with fresh epidote-albite veins.

- (c) **Huarguallá:** here (Litherland, 1987) tectonic slices of blue quartz granite of Tres Lagunas type (see 2.4.3) are followed eastward by 15 m of E-dipping black serpentinite, more sheared and asbestiform towards the base. Over the serpentinite are 5 m of olivine gabbros (fresh clinopyroxene, altered olivine and plagioclase) and spillitic lavas cut by fresh albite veins. The remainder of the section comprises graphitic phyllites, cherts and metabasalts.
- (d) **Guamote-Atillo road:** here the mélange is dominated by black and maroon cherts, slices of blue quartz granite with megacrystic smoky K-feldspar, and somewhat silicified fine-grained metasediments.
- (e) **Río Zula:** here (Map 4) the mélange begins with strongly-sheared, ?silicified, grey and greenish fine-grained rocks and slices of blue quartz granite, followed by a mélange of mudstones and greywackes, with blue quartz and chert clasts, and tectonic and sedimentary breccias. This is followed by a thick vertical sequence of black and white cherts with green fine-grained metavolcanic horizons and metalavas. This sequence shows little mélange features and should perhaps belong to the Maguazo division.

The blue quartz granites noted at Huarguallá, Guamote-Atillo road and Río Zula, are similar to those described in Appendix 6 from the Central belt. They are coarse-grained perthitic biotite-muscovite granites, probably lying in the monzogranite field of Streckeisen (1976), and containing blue quartz. Along the Peltetec division, the incoming of the blue quartz granite slices corresponds to the disappearance of the ophiolite slices.

The conspicuous tectonic feature of the Peltetec division is the presence of subvertical tectonic slices or *mélange*, a feature well-displayed at the best sections: Huarguallá and Río Zula road, where a fairly chaotic mixture of lithologies is exposed, the contacts of which can be seen to be tectonic and parallel to a subvertical cleavage. In this respect the Peltetec division can be distinguished from the Maguazo division to the east where certain similar lithologies may be present but in a more coherent stratigraphic sequence.

The most remarkable geological contact, however, is that to the west with the Guamote and Cebadas divisions. This is marked not just by an abrupt change in lithologies but a change from steep to flat cleavages.

2.2.5 The Maguazo division

This unit has been separated from the previous Peltetec division (Table 1) on account of the presence of a diagnostic turbiditic sequence and the lack of *mélange* tectonics. Other lithologies of this division include cherts and massive andesitic greenstones. Structures are steep and the tectonics of the division represent a continuation of the Peltetec steep belt. The unit can be traced from Penipe in the north to the Río Paute in the south (Map 1) a distance of about 150 km. The following sections were traversed:

- (a) **Penipe:** here (Map 2) the Peltetec division is followed eastwards by a sequence of greenish meta-andesites, metatuffs, cherts, black phyllites and greywackes before passing into more massive andesitic and basaltic greenstones.
- (b) **Alao Valley:** here (Map 3) the Peltetec division is followed eastwards by black slates and orthoquartzites and then by massive meta-andesitic greenstones. Close to the Río Maguazo there are outcrops of black slates and fine siliceous banded turbidites with graded bedding. Way-up structures across this belt indicate a first deformation isoclinal syncline (Map 3).
- (c) **Huarguallá Valley:** traverses on both sides of this valley (Map 3) picked up the same Alao sequence; there are blocks of dark limestone on the north side. Extending the traverse to the SE (Map 3), massive andesites were encountered east of the turbidites and these give way to an andesite/turbidite sequence younging west. It is clear from the section on Map 3 that a stratigraphic column can be proposed for the Maguazo division of this sector with a thickness of over 3 km.
- (d) **Guamote-Atillo road:** here the Maguazo division is manifested by black phyllites, greywackes and andesitic lavas. As at Alao Valley, there are also outcrops of pale or reddish, fine-grained orthoquartzites.

- (e) **Río Zula:** here (Map 4) the Peltetec division passes into thick units of pale or grey, fine-grained marble, followed by the Maguazo-type banded turbidite rock with thin pale and dark limestone bands.
- (f) **Río Paute:** here the Maguazo division is manifested across an up-right, tight, first deformation syncline the axial trace of which follows Quebrada Totorá Yacu which flows south into the Río Paute. Rocks on either side of this syncline comprise banded and graded volcanoclastic turbidites, meta-andesites, black slates, marbles and cherts. Across the Río Paute to the south, the Río Jadan contains turbiditic outcrops and blocks of red chert.

2.2.6 The Alao-Paute division

This is the same as the Alao division of Litherland (1987). “Paute” has been added to indicate that the division encompasses the meta-andesites previously recognised as part of the “Paute Group” (Baldock, 1982). However, this does not indicate the acceptance of this or any other previous formal lithostratigraphic nomenclature for the Cordillera Real.

The Alao-Paute division can be traced from the Baños-Patate section along the Río Pastaza (Litherland, 1987), through the Alao Valley, and the Laguna Atillo sector, to the Río Paute (Map 1), a distance of about 150 km. Lithologies are dominated by massive meta-andesites, with subordinate greenschists, pelitic and graphitic metasediments, and minor dark marbles. Agglomerates are a feature of the outcrops along the Río Paute west of Gualaceo.

In the north, the Alao-Paute andesites are similar, lithologically, to those of the Maguazo division but show a higher metamorphic grade (greenschist facies) and a more complex tectonic history in that the steep penetrative cleavage is a second structure rather than the first. The San Antonio fault (Map 1) marks the contact between the two divisions and the two tectono-metamorphic domains.

Further south in the Paute valley the greenstones appear to be affected by a single steep penetrative cleavage.

2.2.7 The Tampanchi mafic igneous complex

This is probably the first “layered” mafic igneous complex to be recognised in Ecuador. From the brief study carried out, it is an elongate body of 2 km thickness and lying within the Alao-Paute division. On the Cañar geological sheet, Bristow et al. (1975) designated the rocks as “amphibolites”.

The dominant lithologies along the studied road section are fresh magmatic clinopyroxenites and hornblendites. The clinopyroxenites are medium grey-green, medium to coarse-grained rocks comprising cumulate subrounded clinopyroxene and intercumulate green hornblende and rutile. One sample shows partial replacement of the pyroxene by hornblende. The hornblendites are dark green, medium to very coarse-grained, essentially monomineralic rocks, though one sample shows interstitial clinozoisite and muscovite (replacement of plagioclase). Types with primary pale magnesium amphibole show breakdown to talc and asbestos. There are also pegmatitic gabbros with hornblende crystals up to 5 cm long.

These lithologies are cut by acid veins and small diorite stocks. Shears are prominent and may produce serpentinised slickenside planes. Massive serpentinites have not been noted but a mining company geologist, following up this project discovery, reports the presence of a dunite phase.

The contacts of the complex were not studied. The metamorphic rocks to the west comprise fine hornblende schists of somewhat higher grade than the local Alao-Paute rocks. Rocks of similar aspect to these schists were seen in contact with the magmatic units.

2.2.8 The Guarumales division

The status of this division, dominated by greenschists and meta-sediments, remains enigmatic. See 2.4.2 for further details.

2.2.9 The cover sequence of the Western belt

Bristow et al. (1975) claimed that the San Francisco and El Pan “Formations” of the Paute “Group” of the Western belt metamorphic complex are the metamorphosed equivalents of the Cretaceous Piñón or Macuchi Formation and Yunguilla Formations (Maastrichtian) to the west on the Cañar geological sheet.

The present studies show that this cannot be the case. Map 1 indicates that the Yunguilla Formation, which is essentially undeformed and without a penetrative cleavage away from fault zones, and which comprises mudstones, tuffaceous sandstones and tuffs, must unconformably overlie the Guamote, Peltetec and Maguazo divisions of the metamorphic complex, where it outcrops north of Azogues. The confusion may have arisen from the occurrence of fault related cleavages and the presence of essentially undeformed andesites in the Río Dudas sector NE of Azogues. Map 1 shows a geological reinterpretation of this area and other sectors of cover sequences along with newly-located outcrops. The major units are described below:

- (a) The “Macuchi Formation”, as shown on Map 1 is essentially a continental andesite/tuff/agglomerate sequence. Previously known outcrops have been checked near Yaruquíes, Guamote (Columbe Valley) and Río Silante (E of Cañar). New occurrences have been identified along the Río Chambo (S of Licto) and east of Guasuntos.

- (b) The Río Chambo outcrops (Map 3) reveal volcanic and subvolcanic rocks which are intimately related and cut by the adjacent plutons (see 2.2.10). A 70° trending steep fracture can be related to late folds in the Guamote and Cebadas divisions of the Western belt metamorphic complex.
- (c) The volcanics east of Guasuntos (Map 4) are shown on the Alausí geological sheet (Sosa and Longo, 1975) as part of the metamorphic complex intercalated with the “Paute Series”. In reality, although relationships are intimate, they are always tectonic and not stratigraphic. The volcanics, pale grey and pink felsic lavas and porphyries, are massive, undeformed and unmetamorphosed. The tectonic contacts with the black slates of the Guasuntos division, which contain two penetrative cleavages, are along reverse faults trending 70° and with dips of 40° to 90° to the north, so that the slates are found structurally overlying the lavas. Again, this event is correlated with the 70° trending late folding event of the metamorphic basement.

In the south of the area, Map 1 tentatively depicts a sector where andesitic lavas are intercalated with sediments and volcanics at the base of the Yunguilla Formation. Thin lavas were also noted in the Yunguilla Formation in the Río San Pedro east of Cañar, on the western flank of the Yunguilla “basin”. NE of Azogues these Yunguilla lavas are interpreted to unconformably overlie the steeply-dipping meta-andesites of the Alao-Paute division basement; though Bristow et al. (1975) regarded all the andesites as one unit.

It is probable that the lavas at the base of the Yunguilla Formation are equivalent to those mapped as “Macuchi Formation” on Map 1.

The main Tertiary volcanic unit over the area of Map 1 in the Pleistocene Tarqui Formation. A possible feeder for this unit was found as a vertical sheet of pink microfelsitic rocks, ca. 300-500 m wide, and associated with the silicification of the host rock, along the San Antonio fault which divides the Maguazo and Alao Paute basement division in the Alao Valley.

2.2.10 Intrusive rocks cutting the Western belt

The blue quartz granites found as tectonic slices within the Peltetec (mélange) division (see 2.2.4) are regarded as fragments of syn- or pre-tectonic bodies correlated with the Tres Lagunas suite of the Central belt (see 2.4.3). Boulders of the same granite were found within the newly-discovered Alao pluton (Map 3) and are probably derived from a xenolith.

The granodiorite pluton(s) near Pungalá (Map 3), intimately related to the “Macuchi” volcanics; the Alao hornblende-biotite granodiorite, with andalusite contact zone in Maguazo division slates (Map 3); and the Magtayán granodiorite (Sosa and Longo, 1975), all cut the Western belt metamorphic complex, are undeformed, and are provisionally regarded as part of one plutonic chain. Boulders of granodiorite in streams draining west across the Río Cebadas road indicate that this chain is more extensive and may trend south to include the Amaluza pluton (Map 1). K-Ar data from Magtayán (quoted in Litherland, 1987) give 54-85 Ma whilst those from Amaluza give 34-49 Ma.

More microfeldspathic minor intrusives have been mapped over the western belt (Map 4) following the earlier discoveries over the Western and Central belts (Litherland, 1987). The importance of these dykes as a time marker is that they are essentially syntectonic: they cut the regional S1 cleavage in the Guamote division but are themselves cut by the S2 cleavage and involved in the later D3 folding.

2.2.11 Major faults within the Western belt

The most important and fundamental structure of the Western belt is the Peltetec fault. It can be traced from satellite images along the course shown on Map 1. It forms the Río Chambo lineament where basement rocks of the Peltetec division are faulted against Pliocene and Pleistocene volcanic units to the west. To the south, where the fault lineament is traced over the metamorphic rocks, it consistently marks the contact between the Guamote/Cebadas division “flat belt” and the Peltetec (mélange) division. Further south the lineament shows up across the Pleistocene Tarqui Formation and the older, Maastrichtian, Yunguilla Formation. Crossing the course of this fault along the Río San Pedro, east of Cañar (Map 1), there is a steepening of bedding in the Yunguilla Formation rocks and small-scale, low-angled bedding thrusts with westward transport. Thus, it is clear that the old line of the Peltetec mélange has been rejuvenated in the Pleistocene to produce the Peltetec fault and the corresponding strong lineament on imagery.

Another important fault is that of San Antonio (Map 1). This is also a ‘basement’ fault dividing the Maguazo and Alao-Paute basement divisions. Its plane has been utilised to channel Tarqui volcanics (Map 3), and further south it can be traced as a weak lineament on imagery through the small Miocene basin (Biblián Formation) and Tarqui Formation of Pilzhum Mine.

Other ‘reactivated’ basement faults (Map 1) further east are less well defined on imagery. The Tampanchi Complex is probably bounded to the east by the major fault depicted as following the Paute Valley.

The Baños front, the eastern limit of the Western belt, is marked in the NE sector of Map 1 from Baños to the Alao headwaters by lithological changes, increase of metamorphic grade and incoming of blue quartz-bearing granitoids and gneisses. Its trace further south is discussed in 2.4.2.

2.2.12 Interpretation of the Western Belt

Following Litherland (1987), Aspden et al. (1987), Aspden and Litherland (1987) and Aspden et al. (Appendix 8), and with regard to the new data collected, the metamorphic basement of the Western belt is interpreted as marking a collision zone, thus:

- (a) The Guasuntos, Guamote and Cebadas divisions are interpreted as either passive continental margin sediments of the Chaucha-Arenillas continental plate, or later molassic sediments. Whatever their origin they are interpreted to be thrust westwards over the Chaucha-Arenillas plate (Fig. 3 and Appendix 8).
- (b) The Peltetec division is interpreted as a subduction complex marking the suture between the Chaucha-Arenillas terrane and the Alao-Paute island arc terrain.
- (c) The Maguazo division is interpreted as a forearc volcano-sedimentary basin with some oceanic sediments.
- (d) The Alao-Paute division is interpreted as an island arc sequence.
- (e) The Tampanchi mafic igneous complex is interpreted as either the base of the arc or an ophiolite sequence.

Fig. 3 shows that on this model the Maguazo syncline represents the core of the 'steep belt' between the eastward dipping thrust sheets to the west and the westward-dipping thrust sheets of the Central belt to the east. It is likely that the syncline marks the change of vergence of the two thrust belts.

Following the presumed accretion of the Chaucha-Arenillas plate, the new South American continental margin was next 'assaulted' by the accretion of the Nono-Shobol island arc terrain (Megard and Lebrat, 1987) accompanied by the Celica continental volcanic arc of Cretaceous age. It is thus likely that the rocks previously labelled 'Macuchi Formation' (Map 1) are the northward extension of the Celica volcanics and are associated with the Pungalá-Alao-Magtayán plutonic arc. The opening of the Yunguilla Formation basin (Map 1) was probably controlled by extension along the older Peltetec suture. The Nono-Shobol collision along the Calacalí-Pallatanga-Palenque suture (see Appendices 8 and 9) probably accounts for the thrusting of the volcanics east of Guasuntos and the late folding in the adjacent 'flat' metamorphic divisions.

During the Neogene and Pleistocene Andean uplift, the 'collision faults' of the western belt were reactivated and the Peltetec suture became the line of the eastern fault of the Inter-Andean graben. It is also suggested that these faults provided the channel ways for the volcanicity of that period and continue to do so today as manifested by the volcano-chain of the Cordillera Real (see Appendix 8).

2.3 The metamorphic complex between the Papallacta and Pastaza rivers

2.3.1 Introduction

This section is a summary of the results of the work undertaken between the above-named rivers (Map 5) and includes the following geotraverse data from north to south:

- (a) Papallacta-Baeza (Litherland, 1987, Map 5)
- (b) Río Antisana-headwaters of Río Cosanga (this report, Map 6)
- (c) Salcedo-Tena (Río Mulatos) (Litherland, 1987, Map 6)
- (d) Río Mulatos-Río El Placer (this report, Map 7)
- (e) El Triunfo-Cerro Hermoso (this report, Maps 8 and 9)
- (f) Baños-Puyo (Litherland, 1987, Map 8)

For the compilation of Map 5, geological information was also obtained from Merlyn and Cruz (1986) geotraverse along Quebrada El Golpe/Río Niágara, and from Kennerley (1971). A helicopter-supported study of a sector of the Río Chalupas (Map 5) was also undertaken.

Although the 1987-1988 geotraverses did not cross the sub-Andean front into the Eastern belt, the nature and structure of these rocks is important to this summary and is therefore included. New petrographic data on samples collected on the 1986-1987 geotraverses, not available in Litherland (1987), is also presented here.

The Cordillera Real metamorphic complex between the rivers Papallacta and Pastaza comprise mainly Central and Eastern belt rocks along the eastern Andean slope; access is extremely difficult; the area being cut by a series of precipitous river gorges; topographic levels reach 4600m; it rains most of the time.

Serious geological studies prior to this project have concentrated on the Papallacta-Baeza and Baños-Puyo road sections (Sauer, 1958; Kennerley 1971; Trouw, 1976; Herbert, 1977). Geological expeditions have also been made to study the Cerro Hermoso area (Sauer, 1958; Vera and Vivanco, 1983). A trip down the Golpe/Niágara river is also reported in Sauer (1958); this section is confused with the Río Mulatos. Indeed, Sauer can be regarded as the first geologist to appreciate the existence of the many geological units of the area, e.g. basement gneiss and schists, the Cerro Hermoso carbonate sequence; the Azafrán and Abitagua igneous complexes; the Topos-Quijos depression of the present Eastern belt; and the serpentinites, and to realise that the elucidation of the age and interrelationships between these units could provide the geological history of the area. For this reason, he subtitled his 1958 paper 'The geological age of the Eastern Cordillera'.

This section describes the geology and structure of the Río Papallacta-Río Pastaza sector based on the Project studies.

2.3.2 The Alao-Paute division of the Western belt and the Baños Front

This is exposed west of the Baños front north of the Río Pastaza. Rocks are dominated by massive meta-andesitic greenstones, greenschists, graphitic phyllites, pelitic phyllites and thin black marbles. The Baños front, which is now more precisely located across the bridge in front of Baños Zoo, marks the fairly abrupt change from chlorite-muscovite-epidote assemblages, west, to amphibole-garnet assemblages, east. To the east the green rocks are limited and pelitic schists and paragneisses are present with blue quartz veins.

2.3.3 Metavolcanic rocks of the Central belt

These generally occur as amphibole- or chlorite-bearing greenschists or greenstones, although certain isolated occurrences near Papallacta and between Baños and Río Blanco indicate a dolerite dyke protolith. In general terms the more massive amphibolitic greenstones, e.g. along the Río Anatenorio, probably represent metalavas of andesite or basalt composition whilst the chlorite (with or without biotite) greenschists, e.g. Río Chalupas and Papallacta-Baeza road, are probably metatuffs, since in many places, they are intercalated with meta-sediments as thin bands.

2.3.4 Pelitic, psammitic and carbonaceous rocks of the Central belt

These are represented by pelitic schists and phyllites, pelitic gneisses, semi-pelitic gneisses, graphitic schists and quartzites, intercalated with the metavolcanic and calcareous lithologies of the region. Metamorphic index minerals include muscovite, biotite, garnet, chloritoid and kyanite but no medium to high grade rocks have been noted, i.e. migmatitic gneisses or sillimanite schists. Staurolite, the index mineral for pelitic medium-grade Barrovian facies (Winkler, 1976) has yet to be identified. There are differences in metamorphic grade across the area, e.g. from the garnet porphyroblastic schists of Agoyán to the chloritoid phyllites of Cerro Hermoso but no regional trends have been observed and any real understanding of the metamorphic history awaits the elucidation of the thrust-sheet tectonics of the Central belt and thus the definition of individual tectono-metamorphic packets.

Whatever the tectonic complexities of the sector, it is possible that all the rocks of the Central belt, with the exception of plutonic/orthogneiss units, belong to a single thick volcano-sedimentary sequence. Apart from the lithological similarities along the strike of the belt, this is also supported by the presence of diagnostic lithotypes across it. For example, in the “black phyllite” unit of the Cerro Hermoso sequence (Map 9), there are dark-grey, volcanoclastic meta-greywackes which, microscopically, reveal fine-grained acid volcanoclasts with a ferruginous “peppering” which serves to pseudomorph the clast. Identical metagreywackes were noted in the Río Chalupas study area further north, and slightly across the strike.

2.3.5 Calcareous rocks and sequences of the Central belt

Kennerley (1971) indicates the presence of bands of marble within the schists and gneisses of the Río Anatenorio and further south. The present survey (Litherland, 1987, Map 6) followed the road along the Río Anatenorio and it is probable that the marbles are exposed in the river section. It is interesting to note that Merlyn and Cruz (1986) noted river blocks of marble along strike to the south in the Río El Golpe (Map 5).

There is a calcareous sequence of rocks at Cerro Hermoso (Sauer, 1958) and the present survey has produced the first detailed geological map of this sector (Map 9). ‘Way-up’ evidence, cross-bedding and other sedimentary truncations, were utilised to establish a stratigraphic column, ca. 500 m thick with a basal black phyllite/metagreywacke followed by a quartzite, black phyllite and marble, and, finally, a thick, dark calcareous flysch unit. This sequence was thought to overlie, unconformably or tectonically, a metamorphic basement of pelitic schists and Azafrán metadiorite. However, petrographic studies have revealed a common tectono-metamorphic history, manifested especially by the presence of chloritoid-garnet in pelitic units at all levels. Thus, the Cerro Hermoso sequence is considered, stratigraphically, as part of the Central belt metamorphic complex.

Apart from the synclinal ‘outliers’ of the Cerro Hermoso sequence towards the top of Cerro Hermoso itself; there is also a regionally more important, steeply-dipping, westward-younging, tectonic slice to the west which can be traced south to the black phyllite/marble belt of the Río Blanco/Río Pastaza junction, and north to the Río El Golpe where both Sauer (1958) and Merlyn and Cruz (1986) report calcareous rocks. The latter also report an ‘outlier’ of marble over the Azafrán pluton further east (Map 5).

Pale and dark marbles and calcsilicates are also found within the El Placer skarn tectonic packet at differing levels, one at the base of the mafic metavolcanics (see 2.3.6). To the south, in the Río El Golpe, marbles, calcsilicates and metagreywackes (samples from Merlyn and Cruz, 1986) typical of the Cerro Hermoso sequence are indicated below the skarn tectonic packet on Map 5.

2.3.6 Skarns, calcsilicates and associated rocks of the Central belt

A Llanganates “skarn belt” was proposed (Litherland, 1987) based on the petrographic identification (Litherland, 1987, Appendix 5) of skarn blocks from various rivers and stream draining east into the upper reaches of the Río Mulatos. A trip to locate the skarn outcrops was undertaken, and it was decided to follow upstream the Río El Placer for the following reasons:

- (a) It was the nearest tributary with skarn blocks to the departure point.
- (b) It was the river with the smallest drainage basin which contained skarn blocks.

Skarn outcrops were located at the headwaters of the Río El Placer (Map 7), a 1000 m above the junction with the Río Mulatos. The outcrops exhibit a subhorizontal tectonic foliation, in marked contrast to the steep foliation of the schists and gneisses in the Río Mulatos, and are tectonically underlain by a thick packet of massive biotite-porphyroblastic amphibolites derived from a mafic volcanic protolith, with subordinate ultramafics and marbles.

Figure 2 shows a schematic section of the new El Placer skarnfield outcrops as found at various waterfalls. It also refers to rock sample numbers described petrographically in Appendix 5. Other samples described in Appendix 5 come from float blocks, the locations of which are shown on Map 7.

The dominant skarn rock is a mafic skarn of ferruginous amphibole-clinopyroxene-grandite-epidote composition which produce massive outcrops and house-sized blocks on the hill-slopes. They may be pale-pink/green or dark depending on the concentration of amphibole and magnetite. The lowest two waterfalls (Fig. 2) show that these skarns are intimately associated with altered amphibolites (epidote, garnet, magnetite, quartz) similar in composition to the underlying amphibolites. Thus, the skarn protolith is considered as a mafic lava sequence.

Figure 2 also shows other lithologies within the skarn 'sequence' which must be interpreted as tectonic slices. These include meta-andesites altered metadiorites, siliceous marbles, garnet-biotite schists and muscovite-albite-schists.

Most of the units of Fig. 2 show strong sulphide mineralisation and thus a ferruginous weathered surface and this helps to identify lithologies of the El Placer skarn sequence as blocks in the Río Mulatos. Only the garnet skarn (sample No. 137) is too far north to have been derived from the main El Placer skarnfield (Map 7). Sample Nos. 265-269 (Appendix 5) are from the Río Mulatos, whilst Nos 271-281 (Appendix 5) are from the Río El Placer. There are various lithologies including tourmalinite and pink clinozoisite "skarn".

Despite the subhorizontal nature of the El Placer outcrops there are no corresponding photogeological structural expressions to trace the skarnfield to the south: the area is densely forested and structural grains cannot be traced with certainty. That the "mafic skarn" field continues southward is indicated by float blocks of mafic skarn and epidotised metalava in the Ríos Tigre, Niágara Chico and Niágara Grande at their junction with the Río Mulatos and also mafic skarn blocks upstream in the Río Niágara (samples from Merlyn and Cruz, 1986). Map 5 shows a rough approximation of the El Placer skarnfield outcrop and underlying mafic volcanic unit, based on the data available.

As indicated in Appendix 5, the character of the skarn and the alteration and the composition of the igneous rocks within the packet, all suggest that it is an example of a calcic-magnetite skarn association (Einaudi et al., 1981), a widespread association of high level dioritic intrusives in island arc complexes.

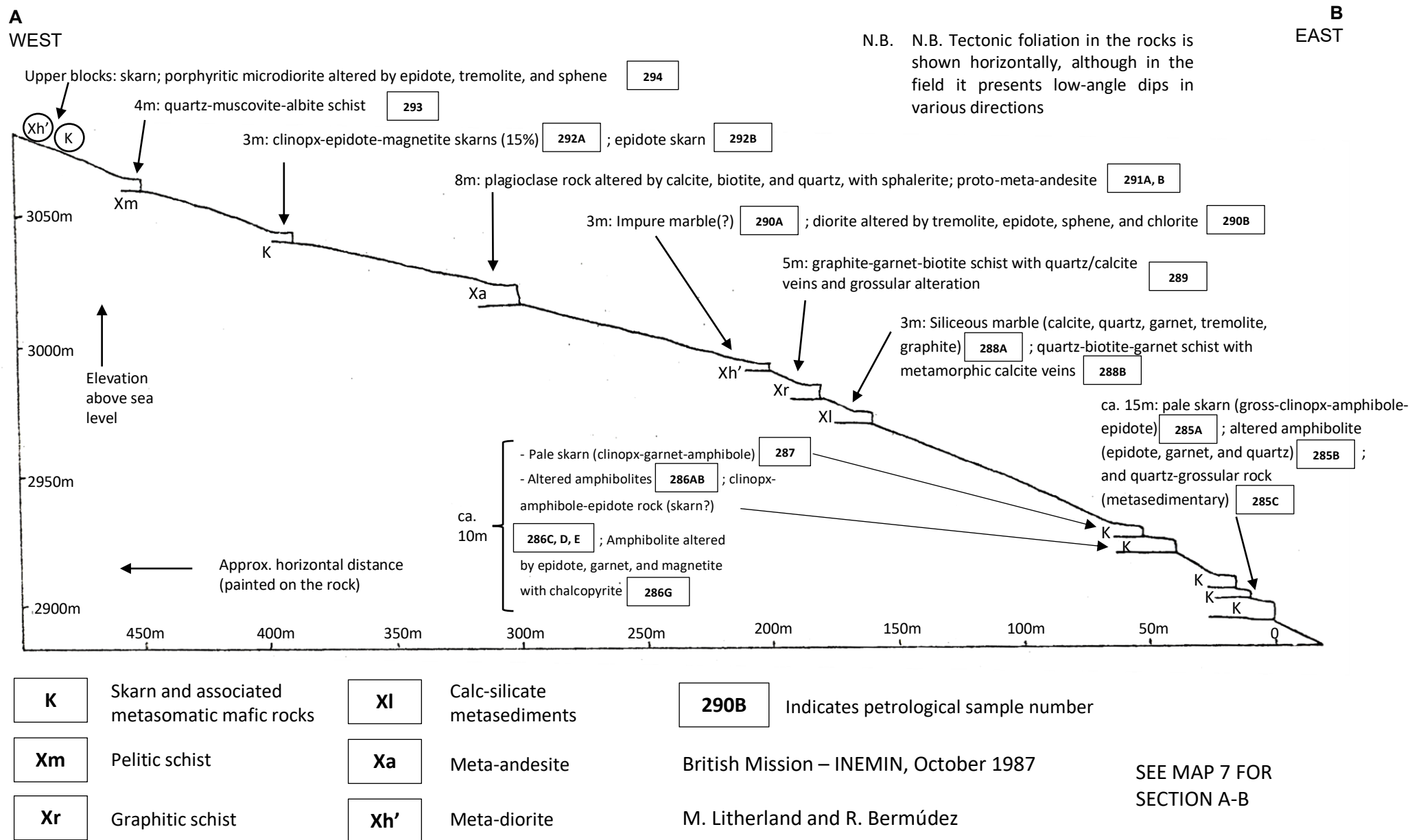


Figure 2. Section of the structurally lower part of the skarn sequence, Quebrada San Martín

South of the El Placer skarnfield, as depicted on Map 5, there are no further outcrops or blocks of mafic skarn. However, close to the eastern fault contact of the Cerro Hermoso sequence (Map 9), there are garnet-rich horizons in certain calc-pelitic beds of the calcareous series. The size (up to 5 mm) and textural relation of these garnets (cutting and wrapped by cleavage) are similar to those in the adjacent schists and also to the andalusites and sillimanites, of undoubted thermal metamorphic origin, in other sectors of Cerro Hermoso. Thus, these pale “calc-silicate” skarns are regarded as contact metamorphic effects of the adjacent Azafrán plutonic complex. Their protolith is not mafic but calc-pelitic. Similar rocks have been noted as river float in the El Golpe river (samples of Merlyn and Cruz, 1986). Andalusite-bearing rocks have also been noted as blocks in the Río Mulatos.

Strongly-epidotised rocks related to metasomatism of the Azafrán diorite phase have been noted as float in the Río Verde and a small eastern stream draining south into the Río Pastaza (Map 5). These are similar to some of the lithologies associated with the El Placer skarn, but no true mafic skarns, Fe amphibole-pyroxene-garnet rocks, were noted.

Immediately north of the El Placer skarnfield (Maps 5 and 7), the rocks in the Río Mulatos are formed of schists and gneisses presumably below the level of the skarn tectonic packet. Float in the Río Zapalá is dominated by the lower mafic unit of the skarn packet indicating that the skarn rocks do not crop out on the SE side of this valley. However, it is likely that the skarnfield crops out further north, presumably at high topographic levels, since skarn blocks were noted upstream (sample No. 137, Map 7), and, further north along strike, skarns have been reported from the Río Chalupas, close to the area of study (Map 5).

Further north it is possible that the same skarn tectonic unit is present as epidote rocks and epidotised mafic lavas found as blocks, along with serpentinites, near the Río Cosanga headwaters and in the Río Quijos near Baeza (see 2.3.7). Some of the metalavas show conspicuous magnetite.

Epidotized mafic volcanic rocks, part of the Alao-Paute or Peltetec ophiolite division have been reported from a basement window along the Río Blanco de Patate (Ing. E. Salazar, personal communication) in the extreme SW of Map 5.

2.3.7 Serpentinites of the Central belt

Prior to this project, river blocks of serpentinite had already been noted from the Río Chalpi (P. Duque, personal communication) and the Río Quijos, near Baeza (Colony and Sinclair, 1932) (Map 5). These authors report a serpentinite outcrop but the project team only confirmed large river blocks. These serpentinites are dark grey-green in colour and show fine antigorite and a prominent carbonate phase. Associated river blocks include monomineralic epidote rocks, similar to those associated with the mafic skarns (see 2.3.6). The blocks are up to one metre across and further work is required to look for Colony and Sinclair’s outcrop or the derivation of the known blocks.

Carbonate-bearing serpentinites of the same dark grey-green colour were found as river blocks along the Río Mulatos (Maps 5 and 7) and in Quebrada de los Incas which drains into the Río Muyo (Maps 5 and 8). The former were first noted in the Río Mulatos to the north of the main El Placer skarnfield, and thus some, and probably all, are not derived from this sector. Indeed, no serpentinite blocks were noted in the Río El Placer. However, outcrops of “diopside skarn” (see No. 274, Appendix 5) of ultramafic character were noted at the base of the sub-skarn mafic unit and it is thus possible that the serpentinites are derived from the north from an extension of this skarn/?ophiolitic tectonic packet. The Quebrada de los Incas blocks have probably come from an ophiolitic packet within the gneisses and schists to the east.

The hunt for serpentinite outcrop was finally rewarded along the Río Antisana-Río Cosanga traverse (Maps 5 and 6). A 6 m lens of the dark grey/green serpentinite was noted tectonically overlain by about 40 m of meta-laminated siltstone (followed by augen-orthogneisses) and underlain by about 200 m of black graphitic phyllites. Further east, across a possible antiformal hinge, the ?same unit is found as blocks of black asbestiform serpentinite, accompanied by asbestos blocks, more reminiscent of the Peltetec serpentinites of the Western belt, and by blocks of epidotised mafic metalavas, and epidote rock (?skarn).

The only other reports of serpentinite come from Sauer (1958), along his “Río Mulatos” traverse. In order to locate these outcrops and blocks it is important to first locate his traverse. In this respect despite topographic names such as Anatenorio, Leones, Langoa Cave and Langoa River, all of which correspond to the present Río Anatenorio-Río Mulatos traverse (Map 7), a glance at his sketch map (Croquis No. 1 de los Llanganates) makes it clear that Sauer traversed along the Río Golpe-Río Niágara and only reached the (present) Río Mulatos at the end of his traverse. Altitudes given in Sauer (1965) support this location. Thus, the localities of Sauer’s serpentinite outcrops (see Map 5) should be located along the Río Niágara before the junction with the Río Mulatos, and further east along the Río Mulatos itself. Suffice it to say that the present survey observed no serpentinite outcrops along the Río Mulatos section. However, on the basis of Sauer’s geological standing, it is probable that they crop out along the Río Niágara (Merlyn and Cruz, 1986, did not reach these low levels) and may have been missed further east along the Río Mulatos. The lower reaches of the Niágara are difficult of access. The Everest mountaineer, Hamish McInnes (1984), had to cross from the Niágara to the Niágara Chico to reach the Río Mulatos owing to the difficulties presented. Thus, any field check on Sauer’s serpentinites requires good weather (low water) and courage.

2.3.8 Granitic orthogneisses of the Central Belt

Granitoid orthogneisses, mainly of biotite-muscovite composition, occur within the regional metavolcano-sedimentary sequence, forming a belt along strike along the western part of the Central belt metamorphic complex between the Papallacta and Pastaza rivers. Indeed Map 5 shows that, at the present state of knowledge, a line can be drawn dividing these outcrops from those allocated to the Azafrán igneous complex (2.3.9) which are dominated by non-granitic lithotypes: diorite and granodiorite.

In all outcrops there is evidence for tectono-metamorphic overprint and the bulk of the rocks can be classified as orthogneisses. In many places the gneissic fabric is marked by augen feldspar/quartz textures.

Outcrops at Papallacta and within the 'antiformal core' along the Río Antisana-Río Cosanga traverse are distinguished by the presence of blue quartz, and, in places, smoky-grey K-feldspar. These are provisionally allocated to the Tres Lagunas suite (2.4.3) found east of the Baños front further south.

The remainder are probably part of the same intrusive phase. Augen gneisses predominate, with or without the presence of smoky-grey feldspar.

Amphibolite dykes were noted in the orthogneisses near Papallacta and east of Cerro Hermoso.

2.3.9 The Azafrán intrusive complex of the Central belt and minor intrusions

This was identified by Sauer (1958) along the Río Pastaza. A quarry in the quartz-monzonite phase along the Baños-Puyo (Río Pastaza) road is now the best-known outcrop.

Prior to this project the Azafrán pluton was considered merely to straddle the Río Pastaza. However, Map 5 shows a considerable extension to the north so that it is possible that the Azafrán body is of similar size, orientation and latitude as the neighbouring Abitagua batholith to the east.

The Project geochronological programme collected nine samples of the quartz monzonite phase from the quarry and nearby (see Azafrán "granodiorite", Appendix 3) for Rb-Sr dating. These give an isochron age 120 ± 5 Ma. Two samples of the Río Verde diorite phase to the west lie off this line at a point suggesting an older age. A block of Río Verde diorite gave a K-Ar age of 171 ± 5 Ma (Litherland, 1987, Appendix 4), whilst previous, and unreliable dates, quoted in Litherland (1987), have given around 175 Ma.

Thus the 120 ± 5 Ma date for the quartz monzonite phase should be taken as a minimum age for the complex, allowing for the possibility that the diorite phase, or the complex as a whole, is older and more akin to the 162 Ma age of the adjacent Abitagua batholith. It must thus be borne in mind that phases of the 'complex' may be of markedly differing ages.

The leucocratic quartz monzonite of the Baños-Puyo road is a homogeneous rock with marginal gneissification. This lithology has not been noted further north where the outcrops and blocks around Cerro Hermoso and along the Río Mulatos are dominated by tectonically-foliated metadiorites and metagranodiorites. The identification of the plutonic phase east of Cerro Hermoso is important since previous maps, e.g. Kennerley (1971), indicate a thrust sheet of calcareous rocks extending across this sector. It is noticeable in this Cerro Hermoso region that the diorite/granodiorite phase becomes less deformed away from the prominent faults (Map 9) regarded as contemporaneous with the steep cleavage/schistosity in the metamorphic rocks.

The westernmost outcrops of the metadiorite phase occur along a narrow belt west of the Walther Sauer fault (Map 9) and this tectonic unit can be traced to the Río Mulatos where outcrops occur within the gneisses and schists immediately below the skarn packet (Map 7). Further downstream along the Río Mulatos there are outcrops or blocks of metadiorite and granodiorite and also dolerite, gabbro and fresh, undeformed, granite and aplite. Mafic xenoliths are common in the main diorite/granodiorite phase. The outcrops and blocks indicate local gneissification and mylonitisation with concordant calcite-quartz-biotite-sulphide veins, but all rocks are cut by later epidotic shear veins.

Further north, similarly deformed granodiorites were noted in the Río Chalupas study area.

Minor intrusives: small pegmatites, aplites, and leucocratic microfeldspathic-quartz-monzonites, found cutting either the Azafrán complex or the country rocks are generally undeformed. The microfeldspathic phase, in places strongly kaolinized, is similar to the syntectonic dykes of the western belt (see 2.2.10) and also some late dykes within the Abitagua granite.

2.3.10 Cretaceous Formations of the Eastern Belt

Around the Río Pastaza-Río Topo area the trace of the Cretaceous Hollín, Napo and Tena Formations (Map 5) is adapted from the relevant INEMIN geological sheets and recent mining company data.

Along the Río Mulatos the cleaved, black, fossiliferous limestone and calcilutites (Litherland 1987, Map 6) are attributed to the Napo Formation, and an exposure gap to the east, corresponding to the incoming of river blocks of fine yellow, red and purple sandstones, dark shales and pale and dark limestone/chert blocks, is regarded, tentatively, as representing the Tena Formation.

The black fossiliferous limestones close to the sub-Andean front near the Río Pastaza (Map 5) have been confirmed, palaeontologically, as Napo Formation age (private sector information).

2.3.11 The Río Mulatos volcanic division of the Eastern Belt

Along the Río Mulatos, the sub-Andean front is marked by the incoming eastwards of grey, cleaved, andesites, porphyries and grey slates. One lava sample collected close to the front is strongly epidotised and resembles certain samples derived from the skarn packet further east. The epidotisation was previous to the final deformation (?sub-Andean Tertiary movement) and is in the form of a breccia.

Further east along the Río Mulatos, passing the probable Cretaceous formations, there is a 9 km wide volcanic belt before reaching the Abitagua granite. This unit produces rugged country similar to that of the granite and has been included with the Abitagua batholith on the INEMIN geological sheet; though Tschopp (1953) made the preliminary differentiation.

Outcrops of this section comprise essentially undeformed porphyritic, silicic ("cherty") and massive acid or intermediate lavas, with agglomerates, flow lavas, and green, cross-bedded, volcano-sedimentary units. Dips, where noted, were between 20 and 50 degrees.

Along the strike of the sub-Andean front from the Río Mulatos outcrops there are green-grey, cleaved, phyllitic metavolcanics, metatuffs and metasediments to the south near the Río Pastaza and to the north along the Papallacta-Baeza road. These are provisionally correlated with the Río Mulatos division. A petrographic feature of one metatuff sample, from the road section south of the Pastaza river at Río Negro, is the presence of ferruginous-spotted volcanoclasts similar to those seen in samples from Cerro Hermoso and Río Chalupas, i.e. from rocks of the Central belt.

2.3.12 The Abitagua batholith of the Eastern Belt

This is a large elongate plutonic body ca. 120 km in length. Its width has now been reduced from that of the INEMIN geological sheets (see 2.3.11). Lithologies are dominated by biotite monzogranites with pink megacrystic K-feldspar. Volcanic xenoliths and late micro-feldspathic, aplite and quartz porphyry dykes are a feature of some outcrops.

The previous geochronological ages of 173 ± 5 Ma and 178 ± 7 Ma (quoted in Litherland, 1987) are close to what most now be regarded as the established age of 162 ± 1 Ma based on the results of the Project geochronological programme (Appendix 3). This age is derived from a 17-point isochron from nine samples collected along a 3 km road section across the Guacamayo Cordillera and seven along the Río Pastaza section. Thus, the Abitagua batholith is of mid-Jurassic age.

Along the Río Mulatos there are small granitoid outcrops and thin feldspathic veins within the Río Mulatos volcanic division close to the main batholith contact, suggesting that the Río Mulatos division is older. The main outcrop shows a xenolithic dioritic western margin intruded by the main pink granite phase further east (Map 5).

2.3.13 Structure of the metamorphic complex between the Papallacta and Pastaza rivers

To say that the structure of this area is complex would be an understatement. In fact, the project studies are only just beginning to reveal possible complexities, i.e. the “tip of the iceberg”. Major tectonic thrust packets are indicated by flat foliations, whilst steep foliations may indicate refolding of these. Despite the inaccessibility, climate and poor outcrop, the importance of structural mapping in the elucidation of the geology and mineral potential cannot be overemphasized, especially since lithological and foliation expressions are photogeologically poor to non-existent.

Working westwards across the area of Map 5, the Eastern belt is essentially undeformed at the Abitagua batholith and the ?older Río Mulatos division immediately to the west. Then follows a belt of Tertiary thrusting of the Cretaceous Formations and Río Mulatos division basement up to the sub-Andean front, another Tertiary structure, perhaps an older structure reactivated in the Tertiary? There are penetrative cleavages in these rocks, especially in the Río Mulatos division greenschists of Baeza and Río Pastaza. The Baeza cleavage is refolded by E-verging folds with steep axial planar crenulation cleavage. It has yet to be determined whether the first cleavage in the greenschists can be correlated with the cleavage in the Cretaceous formation, or is older.

Moving into the Central belt, the tectonics of Cerro Hermoso and the Azafrán igneous complex appears to relate to one event only, manifested by steep faults and related steep cleavages, schistosity and orthogneiss belts. With respect to the structure of Cerro Hermoso (Map 9), it came as a surprise, after finding evidence for the first time for thrust tectonics over many other parts of the metamorphic complex, that such structures were absent over the only area where they had previously been reported (Sauer, 1958; Kennerley, 1971; Vera and Vivanco, 1983). These workers report thrust sheets of flat first cleavages sub-parallel to bedding at Cerro Hermoso, but only simple upright first folds were mapped by the project team (Map 9). This does not entirely rule out a process of pre-cleavage thrusting of sheets which left no tectonic imprint on the rocks. However, if this were the case, the contacts of such sheets should be observable in such a well-exposed sector. Furthermore, the identification of flat tectonic foliations within thrust sheets further east must point to the probability that the Cerro Hermoso rocks have undergone only one phase of deformation associated with a steep cleavage, and are thus autochthonous.

Further north, samples of the Chalupas volcanoclastic meta-greywacke, which shows petrographic affinities with the Cerro Hermoso greywackes, show, microscopically, the presence of only one penetrative cleavage. Thus an “autochthonous” belt with steep first cleavage, can be proposed for the Cerro Hermoso-Chalupas eastern margin of the Central belt (Fig. 3).

Moving further west from Cerro Hermoso there are two important faults or thrusts which can be tentatively traced to the Río Mulatos and which mark important changes in the stratigraphic and tectonic pattern across the Central belt.

The eastern of these faults, the Walther Sauer fault of Map 9, dips about 70° to the west and marks a major thrust of Azafrán metadiorite over a westward-younging Cerro Hermoso sequence. The western fault marks the incoming of the granitic orthogneisses and the apparent division of these rocks from the Azafrán complex. The rocks to the west, ortho- gneisses, schists, etc., are marked by a steeply-dipping tectonic foliation, which, in the schists, can be identified as postdating earlier foliation(s).

Traced to the north (Map 5) these faults are shown bifurcating and enclosing the El Placer skarn tectonic packet of subhorizontal foliated rocks, amongst which the schist units indicate at least second foliations, over steeply dipping gneisses, schists and Azafrán metadiorites. Diorites are also found within the skarn packet. The base of the skarn packet is marked by the incoming of marbles and the amphibolitic metalavas above mylonitic semi-pelitic gneisses, metadiorites and graphitic schists with moderate foliation dips to the west (Map 7). It is thus possible that the eastern fault is folded round the base of the packet and does not continue north as depicted on Map 5. It ceases to be a major lineament on LANDSAT imagery at this point. The skarn rocks are believed to have postdated an early tectonic fabric (Appendix 5), and float block studies indicate a later, localised gneissification event.

Thus, the only reasonable interpretation for the El Placer skarn tectonic packet is as a thrust sheet.

Further north, along the Río Antisana-Río Cosanga traverse, tectonic foliations (second structures) are moderate-to-shallow dipping and pick out a series of major thrust sheets refolded into a gentle antiform. This tectonic packet appears to conform to the following:

TOP:	orthogneiss. serpentine/black phyllite/volcanic greenschists/epidote rocks
BASE:	blue quartz orthogneiss

Further east the photographs show well-defined foliations dipping gently to the east (Map 5).

Further north, between Papallacta and Baeza (Litherland, 1987; Map 5) mapping of the main schistosity (second or third), defines an important flat belt which can only be interpreted as a major overthrust or nappe.

The Baños front is only exposed in the SW sector of Map 5. This is a steeply-dipping ?thrust structure marking the eastern limit of the Alao-Paute division of the Western (collision) belt (2.2.6). A steep second cleavage is prominent in these rocks associated with major upright folds which refold an earlier bedding/S₁ foliation of probable original subhorizontal attitude.

2.3.14 Interpretation of the metamorphic complex between the Papallacta and Pastaza rivers

In section 2.2.12 the Western belt was interpreted in terms of collision plate tectonics. Following this model the Alao-Paute island arc sequence shows an eastern tectonic contact, the Baños front, against the Central belt metamorphic complex described here. This complex contains large scale thrust sheets, which must be related to continental collision processes and the logical assumption would be that the lithological and structural patterns of the Western and Central belts relate to the same collision event. However, based on the present knowledge, this statement cannot yet be made. The following points explain why:

- (a) **The age or ages** of the metamorphic rocks are unknown. The Western belt divisions are unconformably overlain by Maastrichtian sediments and volcanics (70 Ma). The andalusite, sillimanite and large garnets of the Cerro Hermoso sector probably indicate thermal metamorphism by the Azafrán pluton with a minimum age of 120 Ma. In the east the evidence suggests that the Río Mulatos volcanic division is cut by the Abitagua granite (162 Ma). This division shows petrographic affinities with Cerro Hermoso and Chalupas rocks. This, and the presence of the calcareous Cerro Hermoso sequence suggests a possible correlation with the Santiago formation (?Triassic-Lower Jurassic) of the Oriente which is intercalated with volcanic rocks to the west (Tschopp, 1953). It is noteworthy that west of Baeza, there is little change in composition across the sub-Andean front from one greenschist to another.

- (b) **The role of Tertiary tectonism** has to be understood. Clearly Tertiary faults or thrusts dominate the outcrop pattern westwards to the sub- Andean front. But do they affect the rocks found further west? Probably not, since the contact-metamorphic andalusite/sillimanite/garnet at Cerro Hermoso is syntectonic vis-a-vis the regional cleavage and associated faults, and these minerals almost certainly relate to the 120 Ma Azafrán complex. Thus, the sub-Andean front may represent a reactivated older structure. Sauer's (1958) serpentinites lie close to it and the serpentinite blocks of the Río Quijos may be derived from this line. There is thus a hypothetical ophiolitic suture here.

- (c) **Further work** over the Central belt will have to take into account the possibility of erecting a tectonic column of thrust sheets or nappes and look for evidence of overall tectonic transport to formulate a plate tectonic model. Ideal markers include the serpentinites, skarns, marbles and (?collision-related) blue quartz metagranites. The skarns are of island arc affinity (Appendix 5) and are associated with mafic lavas. Slices of marbles and calc-silicates are also present but cannot necessarily be correlated with the Cerro Hermoso sequence. In the north it appears that the serpentinites are found with epidotised lavas of skarn-type. Thus, a folded obducted ophiolite could be proposed with or without mafic lava skarns and marbles. This could be a slice of the Peltetec-Alao-Paute sequence from the west, from a back arc marginal basin, or from the Azafrán 'arc' to the east, whence autochthonous epidotic rocks have been noted. If an alpine-type scenario is present, e.g. Dewey et al. (1986), then above the subducted ophiolite mélange, higher-grade rocks derived from the base of the overthrusting continent could be expected. Figure 3 shows one possible 'alpine' model for the area under consideration. Further east along the Río Antisana-Río Cosanga traverse (Map 5) there is an area of massive 'unfoliated' rocks which apparently tectonically overlies the ophiolitic unit. This appears to be the appropriate sector for finding overthrust high-grade rocks from the base of the colliding continent.

2.4 The metamorphic complex between the Río Paute and the Peruvian border

2.4.1 Introduction

This section is a summary of the results of the work undertaken over the above area (Map 10) and includes the following geotraverse data from north to south:

- (a) Sevilla de Oro-Copal-Méndez (this report, Map 11)
- (b) Santa Teresita-Arenillas; Maylas-La Merced (this report, Map 12)
- (c) Sigsig-Santa Bárbara; Principal-Tres Lagunas (this report, Map 13)
- (d) Limón-Gualaceo (Litherland, 1987, Map 13)
- (e) Sigsig-Chigüinda; Sigsig-Peggy Mine (Litherland, 1987, Map 14)
- (f) Gima-Nueva Tarqui; Gima-Chigüinda (this report, Map 14)
- (g) Oña-Tres Lagunas-Yacuambí-Yantzaza (this report, Map 15)
- (h) Saraguro-Loja (Litherland, 1987, Map 15)
- (i) Saraguro Loja: new road (this report, Map 16)
- (j) Catamayo-Loja-Zamora (Litherland, 1987, Map 16)
- (k) Loja-Malacatos basin-Quilanga (this report, Map 17)
- (l) Valladolid-Porvenir (this report, Map 18)
- (m) Loja-Zumba (Litherland, 1987, Map 17)
- (n) El Chito-La Cruz (this report, Map 19)

Map 10 also incorporates certain information from published INEMIN geological sheets in the west, and a provisional LANDSAT 1:250000 imagery interpretation by Ing. F. Jiménez, in the east. It includes a portion of the Western belt of the Cordillera Real metamorphic complex, but mainly covers rocks of the Central and Eastern belts.

Litherland (1987) used certain informal lithological divisions to describe this sector. These have largely been replaced or augmented by others as indicated in Table 2.

Table 2. Subdivisions of the southern metamorphic complex
from West (Top) to East (Bottom)

Litherland (1987)	This report
Alao greenstone and metasedimentary division	Alao-Paute greenstone and metasedimentary division
Guarumales greenschist division	
	Tres Lagunas granite suite
Loja phyllitic semi-pelite division	Loja phyllitic semi-pelite division
Zumba gneiss and schist division	Sabanilla basement complex
	Sub-Andean volcano-plutonic division
	Older metasedimentary division Eastern belt
	Cretaceous formations of the Eastern belt

The following description of these divisions moves from west to east across the area of Map 10.

2.4.2 The Alao-Paute division and the Baños Front

These are indicated on the extreme NW of Map 10 to the west of the Baños front, a tectonic line defined in this area by the incoming eastwards of rocks of the Tres Lagunas suite and Loja division. The line differs from that of Litherland (1987) which divided the Alao and Guarumales divisions. We now prefer to include the Guarumales greenschists within the Alao-Paute division. Thus, on Map 1 the Guarumales division should be included with the Alao Paute rocks.

The Alao-Paute rocks west of the Baños front as shown on Map 10 are part of an extensive 5-7 km wide, steeply-dipping, mylonite belt. The Baños front is shown as the eastward change from Alao-Paute type green rocks to rocks of the Tres Lagunas suite and Loja division within these mylonites. North of the Gualaceo-Limón road there appears to be some tectonic mixing of these units. Meta-andesites and chloritoid-bearing meta-tuffs can be recognised in the mylonitic Alao-Paute division sequence along with metasediments and possible meta-agglomerates.

2.4.3 The Tres Lagunas granite suite of the Central Belt

Rocks believed to belong to this suite were first encountered at Papallacta and then at Peggy Mine: the “blue quartz” metagranite chain of Litherland (1987), but exposures and field relationships are best exhibited at the Tres Lagunas body, first mapped by Kennerley et al. (1973). Thus, the suite as a whole has been named after this locality.

Mapping during the 1987-1988 field programme has now confirmed a discontinuous belt of these bodies extending from the Río Collay in the north to the Tertiary Malacatus basin basement in the south. The northward extension of this belt can be traced through the blue quartz granites of the Licto-Huamboya geotraverse (Litherland, 1987) as far as Papallacta (see 2.3.8) and probably continues to the Colombian border in the form of the Chingual and La Bonita plutons (Litherland, 1987).

In the south the suite consists of plutonic and meta-plutonic rocks, the eastern limit of which both intrudes and is confined by the western limit of the Loja division. The western limit of the Tres Lagunas suite is less well defined due to the thick cover of younger volcanics. However, in the Sigsig area the appearance of these rocks coincides with the disappearance eastwards of the greenstones and related metasediments of the Alao-Paute division, i.e. along the Baños front. Further north, with the exception of the granitic slices in the Peltetec mélange (2.2.4) and xenoliths in the Alao Pluton (2.2.10), all the outcrops occur east of the Baños front.

The Tres Lagunas suite is normally intensely deformed and typically these rocks occur as gneisses, augen gneisses, schists and semi-schists. In most of the smaller plutons the igneous nature of the protolith has been largely destroyed but lenses of less-deformed ‘gneissic granite’ can usually be recognised. In contrast, in the Tres Lagunas pluton, relatively large areas of completely undeformed intrusive are preserved away from shear zones. It is clear that the major process affecting the Tres Lagunas suite was one of regional shear along a series of Andean-trending faults and that the foliated rocks are essentially mylonites/cataclastites which may extend for several kilometres across the strike. Foliation dips throughout the Andean-trending Tres Lagunas suite are uniformly to the west and vary from moderate to steep.

No whole-rocks analysis is available for the Tres Lagunas suite but compositions appear to be restricted, ranging from granodiorite to granite. Hornblende is absent and the major mafic phase consists of biotite which frequently contains rutile and is typically a red foxy brown in colour. Muscovite is also common and is either present as sericitic alteration of plagioclase or as larger single crystals. In some ‘greisen like’ samples muscovite replaces biotite as the major ‘mafic’ mineral and it is typically pale green in colour and weakly pleochroic. Plagioclase is in many samples seen as subhedral, altered, cream-coloured crystals, whereas K-feldspar occurs as large (up to 14 cm in length), blue-grey megacrysts which may contain inclusions of both plagioclase and biotite. The K-feldspar is often perthitic and relatively fresh (see also Appendix 6).

In hand specimen some samples of the Tres Lagunas suite can be seen to contain brightly-coloured, pale-blue crystals of quartz but the origin of this coloration is not known. In thin sections quartz only very occasionally contains ?rutile needles and it may be that blue colour is due to internal shear since, as noted above, the Tres Lagunas suite is strongly deformed in places.

Significantly the vast majority of samples examined also contain garnet, often as euhedral grains, and, in some of the muscovite-rich varieties, cordierite has also been tentatively identified. In many places tourmaline is also associated with the Tres Lagunas suite where it occurs both as pegmatitic veins or patches, or more rarely as isolated single crystals within the granite.

The age of the Tres Lagunas suite is unknown. Two K-Ar ages for the Tres Lagunas pluton, quoted in Litherland (1987), give 76 ± 1 Ma and 173 ± 4 Ma. The present Project Rb-Sr studies on four samples from river boulders near Peggy Mine (Appendix 3) failed to define an Rb-Sr isochron and the errorchron age of 82 ± 28 Ma from three samples is believed to be a reset age.

With regard to the origin of the suite, the mineralogy (Appendix 6) shows the characteristic of 'S'-type granites. Field evidence indicates that they contain both sedimentary and volcanic xenoliths and at present we suggest that they represent crustal anatectites which were formed as a result of a collision episode of unknown age. Although samples collected from the Peggy Mine area failed to define an isochron these rocks give an initial strontium ratio intercept of 0.7176 ± 0.0014 (Appendix 3) and this high initial ratio would also suggest a strong crustal influence in their genesis.

2.4.4 The Loja phyllitic semipelitic division of the Central Belt

This division dominates the Central belt metamorphic complex in the south. It comprises a thick, monotonous sequence of generally impure fine- to medium-grained quartzites, meta-siltstones, graphitic phyllites, slates and occasional metagreywackes. To the south of the Gualaceo-Limón road there is a marked absence of green rocks of metavolcanic affinity, and it appears that the entire sequence was derived from a continental source. Unfortunately, no sedimentary structures have been noted as an aid to way-up, lithostratigraphy and sedimentary provenance.

To the north, however, e.g. along the Sevilla de Oro-Copal traverse (Map 11), there is an apparent change along the strike in the Loja division marked by the incoming of metavolcanic rocks and also by an apparent increase in metamorphic grade. The still-dominant semi-pelitic and pelitic rocks in places carry coarse metamorphic biotite and/or muscovite, in contrast to the slates in the south, whilst the metavolcanic units are greenschists with, in places, the development of tremolite-actinolite.

Further north, along the Paute-Mendez and Guamote-Macas traverses (Litherland, 1987, Maps 11 and 12) the volcano-sedimentary sequence is maintained in the Central belt; indeed, along the Paute-Méndez geotraverse it is difficult to distinguish this sequence from that of the Alao-Paute (formerly Guarumales) division of the western belt and it may be that a single lithostratigraphic unit is involved. It appears that in the south the Loja division was deposited in a relatively stable environment whereas in the north the presence of volcanic material indicates a more active tectonic setting.

The Loja division rocks generally exhibit a steep to vertical cleavage related to Andean-trending D2 folds. However, along the western margin of the division both cleavage and bedding show gentle to moderate dips to the west and minor 'Z' folds seen in some sections (looking north) would suggest overall eastward tectonic transport. More detailed work is required to establish the precise structural relationships between this "flat foliation belt" (Map 10) and the steeper structures in the east of the Loja division.

The age of the Loja division is unknown. In the area around La Paz (Map 15) the rocks are intruded and hornfelsed by the plutons belonging to the sub-Andean volcano-plutonic division which are believed to be predominantly Jurassic in age (see 2.4.7).

2.4.5 Post-tectonic plutons and minor intrusives of the Western and Central belts

Within the Western and Central belts of the Cordillera Real there are a number of stocks and small plutons which cut the metamorphic rocks but are themselves essentially undeformed. Thus, they provide a minimum age of metamorphism in the Cordillera. The location of these plutons, together with their radiometric ages (excluding K-Ar plagioclase dates which are considered unreliable) are shown on Map 10 and, as can be seen, with the possible exception of the San Lucas pluton, which may, in part, be latest Cretaceous in age, all the plutons are Lower Tertiary in age. No detailed chemistry is available for these plutons, but all carry both biotite and hornblende and, based on hand specimen identification, are predominantly granodioritic-tonalitic-quartz monzodioritic in composition.

In addition to the above, minor felsic and/or silicic high-level intrusions are common and although these tend to be concentrated in the west, in some areas they extend throughout much of the Cordillera, e.g. along the Ríos Altar and San Pablo (Map 14) and east of Chigüinda (Map 11).

Such intrusives are especially common along the Baños front and some of the larger bodies are shown on Map 10. In the Río Collay area, hornblende-biotite-bearing porphyries occur and further to the south (Litherland, 1987, Map 14) the road to Peggy Mine cuts across a tuffaceous breccia pipe. In addition to these sub-volcanic stocks and plugs, felsic dikes are also common.

No ages are available for these minor intrusives but they are generally considered to belong to the Pleistocene Tarqui Formation (Baldock, 1982).

2.4.6 The Sabanilla basement complex

This unit, previously referred to as the Zumba division (Table 2), crops out along the Loja-Zamora road to the east of Sabanilla, and also to the south of Yangana, between the Nudo de Sabanilla and Palanda along the road to Zumba. The presence of these rocks have also been confirmed to the east of Valladolid and Yangana and to the west of Palanda and Zumba (Map 10). Traverses carried out to the north of the Loja-Zamora road have so far not located the extension of the Sabanilla basement complex which is therefore assumed to pinch out northwards.

The outcrop expression of this complex is remarkable in that although it can be traced for some 150 km in a N-S direction it nowhere exceeds 10 kms in width. In those areas where the eastern and western margins have been field checked they coincide with two major sub-parallel regional lineaments which are particularly conspicuous on the satellite imagery over the southern part of the Cordillera Real.

Although no attempt has been made during this study to sub-divide the Sabanilla basement complex into its component units, it is evident that it represents a compound division which has a long and complex geological history. It consists essentially of medium to high-grade gneisses and, in part, migmatites, which together form a distinctive unit that can be clearly separated from the generally much lower-grade, and probably younger, metamorphic rocks which occur elsewhere in the Cordillera.

To the east of Sabanilla and to the south of Yangana the western margin of complex consists of steeply-dipping to vertical gneissic quartzites which pass eastwards into tonalitic-?granodioritic biotite (with or without muscovite) orthogneisses. In the Sabanilla quartzites, fibrous sillimanite can be seen microscopically to be growing along the main cleavages and minor grains of perthite have also been identified. It may be significant these same quartzites, also contain both muscovite and biotite. The presence of muscovite and sillimanite in the same rock indicates that these rocks have undergone at least two phases of metamorphism.

Within the tonalite orthogneisses foliation is variably developed but irregular streaks and clots of biotite are very common and quartz-rich xenoliths are preserved in places. In addition, in many places, this rocks contain ?late-stage segregations of quartz-feldspathic material. Pseudomorphs now consisting of white mica aggregates, possibly after cordierite, have also been identified in some thin sections.

Further to the east, towards Zamora, migmatitic gneisses, which include high-grade, sillimanite-kyanite, streaky biotite gneisses are present (see also Trouw, 1976). Around Valladolid and to the north, amphibolite gneisses, with or without biotite, are common, and at several localities there are outcrops of garnet-biotite-muscovite gneisses. Staurolite-bearing gneisses occur to the north of Palanda over an area where muscovite and/or biotite pegmatites are common. Further north, in the Nudo de Sabanilla sector, there are minor unfoliated muscovite-tourmaline-garnet pegmatitic leucogranites associated with two-mica, garnet-bearing orthogneisses. Elsewhere, generally unfoliated leucogranitic veins and segregation have been observed cutting quartz and/or biotite-rich migmatitic paragneisses.

Structural readings within the Sabanilla basement complex are normally steep and Andean-trending. The existence of refolded minor folds in gneisses exposed along the Zamora road, and the presence of randomly orientated “agmatitic” blocks of biotite-rich streaky tonalitic gneiss set in a matrix of tonalitic orthogneiss indicate a complex history.

The eastern margin of the complex is well-exposed to the east of Valladolid where structural dips are relatively gentle to the west. Here it can be proposed that the complex is overthrust eastward over the “older metasediments” of the Eastern belt (see 2.4.8).

No reliable age determinations are available for the Sabanilla rocks, but the presence of migmatites and medium to high-grade assemblages suggest a Precambrian age. Samples collected by the Project (Appendix 3) from the tonalitic orthogneisses east of Sabanilla failed to define a Rb-Sr isochron but suggests a minimum (reset) age of about 233 Ma with a high initial strontium ratio intercept of 0.7121.

2.4.7 The sub-Andean volcano-plutonic division of the Eastern Belt

This includes the extensive Zamora and Río Mayo batholiths, shown as a single body on Map 10, and what are considered to represent their associated volcanic and sub-volcanic products. Further north it includes an unnamed intrusive to the east of Limón/Méndez (information from F. Jiménez). The division can be extended further north to include the Abitagua batholith and Río Mulatos volcanic division of Map 5 (see 2.3.11 and 2.3.12).

Petrographically this division has not been studied in detail but preliminary data, based largely on field identification, indicates that the plutonic phase ranges in composition from hornblende (with or without biotite) diorites and quartz diorites, to tonalite/granodiorite. Granites are conspicuously absent. Hornblende and biotite are the main mafic phases; muscovite has not been noted.

The volcanic fraction is dominated by feldspar microporphyritic andesites and hornblende andesites. Dacitic lavas are also present and, in some areas, e.g. to the west of Copal (Map 11), coarse volcanic breccias and agglomerates are common.

Minor high-level, sub-volcanic intrusives are widespread and in many places, these are associated with zones of silicification, epidotisation or feldspathisation. The intrusives appear to consist largely of felsites and/or dacites but also include quartz and/or feldspar porphyries.

West of Copal (Map 11), recrystallised, pale, blue/grey limestones occur interbedded with the volcanics, and minor, pale grey, tuffitic phyllites are also present. Further south, west of Limon, strongly sheared andesites and cleaved felsic volcanics (?tuffs) are found together with phyllites, graphitic in places, and minor impure quartzites. However, further south, west of Gualaquiza, sedimentary intercalations are rare in the volcanics and it may be that over the southern part of the division the volcanism was essentially sub-aerial.

Deformation within this division appears to be localised, with development of cleavage and “metamorphism” restricted to narrow Andean-trending zones. To the west of Gualaquiza, for example, sheared “metavolcanics” occur together with massive non-cleaved volcanics which show little or no metamorphic overprint. Equally, to the west of Copal, original feldspar and, in some places, hornblende phenocrysts are preserved but are clearly affected by cleavage refracted around the grains to form “micro-augen”. Incipient recrystallization of the groundmass and around the edges of original phenocrysts is common, whilst chlorite and epidote are found along shear planes.

Structurally the sub-Andean zone, or Eastern belt, is considered to consist of an imbricate series of westward-dipping reverse faults, steep in the west to moderate in the east. These fault movements are thought to be mainly responsible for the deformation and dynamic metamorphism seen along the eastern foothills of the Cordillera. Between the western margin of the Río Mayo batholith and the Tertiary Zumba basin (Map 10), near the Peruvian border, there is a belt of subvolcanic rocks mainly of quartz and/or feldspar porphyries which may relate to faults controlling the eastern margin of the Zumba basin.

With regard to the age of the sub-Andean volcano-plutonic division, a single sample of porphyritic hornblende-quartz-monzodiorite from the Guaysimi area of the Zamora batholith gave a K-Ar age of 151 ± 5 Ma (Litherland, 1987). Another K-Ar date, for the Zamora batholith, not quoted in Litherland (1987), gave 171 ± 6 Ma (Aly, 1980).

Project Rb-Sr studies (Appendix 3) are extensive over the Zamora batholith. Five samples of diorite/quartz monzodiorite from the Río Mayo batholith to the south of Palanda define an isochron of 144 ± 35 Ma. The high error is probably due to the basic nature of the samples and hence the small spread of Rb-Sr ratios, and it is expected that K-Ar analysis of mineral separates will provide a better estimate for the age of these samples.

Rb-Sr samples collected from the Zamora batholith (Appendix 3) failed to define isochrons. However, the best estimates are as follows:

- (a) Granodiorite/quartz-monzodiorite samples from the NW sector of the batholith (Napurca pluton) collected from the road leading to La Paz suggest an age of ca. 185 Ma.
- (b) Compositionally-similar samples from the Cordillera del Cóndor to the east of Paquisha suggest an age of 198 ± 34 Ma.
- (c) Granodiorites (adamellites) collected from the Río Pituca to the SE of Zamora suggest an age in excess of 225 Ma which would indicate an older age for this part of the batholith.

Taken together, the radiometric data indicates that the sub-Andean volcano-plutonic division certainly contains Jurassic elements, but may include older, Triassic, phases. Calc-alkaline lithotypes and low initial strontium ratios for Zamora, Río Mayo and Abitagua (Appendix 3) indicate I-type intrusives, derived from the mantle or by subduction zone underplating. Further mapping and geochronological studies will be required in order to determine the precise age relationships of the rocks.

2.4.8 The older metasedimentary division of the Eastern Belt

To the east of Valladolid and in the Río Isimanchi east of Zumba there are outcrops of low-grade sedimentary rocks, which all lie to the east of the Sabanilla basement complex. Close to the contact, east of Valladolid, the dominantly metasedimentary rocks dip at 30° to the west parallel to the foliation dip in the Sabanilla basement complex close by. Thus, the contact is interpreted as an eastward thrust of basement complex over “cover”.

The division is composed, principally, of generally steeply-dipping metasediments which include phyllites, metasilstones, quartzites and marbles. The marbles may be discontinuous but where seen they form a series of spectacular hills some of which have developed typical karstic scenery (caves, potholes, etc). The marbles vary from blue to off-white in colour and those to the west of Porvenir seem to be particularly pure.

Where the trail from Porvenir crosses the Río Numbala (Map 18), massive breccias are exposed in a relatively clean quartz-rich matrix. The clasts, which are typically between 2 and 4 cm across are composed of cleaved semi-pelites.

Although petrographic studies have yet to be undertaken, it is possible that minor bands of meta-volcanic rocks occur in the form of green phyllites and schistose phyllites.

With regard to age, the contact of this division with the Río Mayo batholith has not been seen, but as one approaches the intrusion the rocks become intensely silicified and hornfelsed. Thus, the entire sequence is considered to be either of lower Jurassic or older in age.

2.4.9 Cretaceous Formations of the Eastern Belt

These rocks, which have not been studied in any detail, comprise both the Cretaceous Hollín and Napo formations which respectively form the major oil reservoir and, probably, the main hydrocarbon source rocks in the Oriente of Ecuador.

In the north (Map 10), both formations are exposed along the Eastern belt where they are deformed and cleaved.

In the south blocks of clean, white Hollín-type sandstones are present NE of Chito (Map 19) and imagery studies indicate that these ?Hollín sandstones overlie, with marked unconformity, the volcanics of the sub-Andean volcano-plutonic division.

Extensive outcrops of unmetamorphosed Hollín Formation have been reported to the east of Porvenir and in the upper reaches of the Río Vergel east of Palanda (Ing. G. López, personal communication), but these areas have not been field checked by the Project.

2.4.10 Serpentinities

A small quarry on the road east of Zumba is composed of serpentinites, olivine pyroxenites, tremolitic ultramafic rocks and gabbros. The outcrop (Map 10) is situated close to a N-S fault defining the eastern limit of the Tertiary Zumba basin against the older metasedimentary division of the Eastern belt.

2.4.11 Interpretation of the metamorphic complex between the Río Paute and the Peruvian Border

Although the metamorphic geology of the Cordillera Real and the sub-Andean zone can be divided into various informal divisions, the relationship between these, particularly in terms of age, remains largely unknown. In view of this any interpretation of the geological history of these rocks must necessarily be of a preliminary nature but with this in mind the following observations can be made:

The sub-Andean zone is dominated by plutonic/volcanic rocks which are considered to be largely Jurassic in age. Radiometric age data from the Zamora batholith however indicates that older elements may also be present within this belt. Mineralogically and isotopically these rocks are “I-types” and are considered to represent the magmatic products of subduction zone-related magmatism. In regional terms the sub-Andean front may represent a zone of crustal weakness which at depth corresponds to the western limit of the Precambrian rocks of the Amazonic craton: the then continental margin of South America. If such an interpretation is correct then it follows that the sub-Andean volcano-plutonic division was emplaced into the western margin of the Amazonic craton and therefore the suite may have certain characteristics in common with the (younger) coastal batholith of Peru.

In the south the Río Mayo batholith intrudes what is referred to as the older metasedimentary division (Map 10). Accepting the Jurassic age for the intrusive gives a minimum age for the older, dominantly meta-sedimentary, unit. Both the Cretaceous Hollín and Napo Formations are unaffected by the main cycle of magmatism which gave rise to the sub-Andean volcano-plutonic division and to the east of the Río San Francisco, just inside the Peruvian frontier, preserved Hollín quartzites overlie with spectacular unconformity the andesitic volcanics that are associated with the Río Mayo batholith.

Field observations across the sub-Andean front suggest that, structurally, it corresponds to a series of generally steep westerly-dipping reverse faults which probably have a long history of movement. The presence of local Andean-trending shear zones and/or linear belts of cleavage and associated low-grade dynamic metamorphism not only within the Hollín and Napo Formations but also, especially in the north, within the Jurassic volcanics of the Eastern belt, can all be ascribed to movements along those faults which define the sub-Andean front, the latest of which was of Tertiary age.

Within the Cordillera Real the oldest rocks recognised belong to the Sabanilla basement complex and are of probable Precambrian age. The narrow elongate form of this unit and the observation that its eastern and western limit, correspond to major regional fault lineaments are noteworthy. Although it is possible that this complex could represent the upfaulted edge of the Amazonic craton it is equally possible that it is an allochthonous block that was structurally incorporated into the Cordillera Real probably sometime during either the Lower Mesozoic or Palaeozoic.

The Loja division is the most widespread of the metamorphic units, the eastern limit of which coincides with the sub-Andean front in the north and the Sabanilla basement complex in the south. Its western limit is defined by the Baños front and the Las Aradas fault. This fault not only defines the structural limit of the metamorphic complex in the south but also separates the Andean trending rocks of the Cordillera from the east-trending Paleozoic and ?Precambrian sequences in the northern part of El Oro Province (Appendix 8).

Intruded along the western margin of the Loja division is a regional suite of 'S-type' granitoids, the Tres Lagunas suite (Map 10). The recent discovery that these plutons also exist to the south of Saraguro is important since if one assumes that the entire belt was generated during the same event, probably collision involving continental material to the west, then it follows that the Las Aradas fault must have represented the approximate southern continuation of the Baños front. In the north the meta-volcanics and metasediments of the Alao-Paute division lie to the west of the Baños front, but as yet, the presence of these rocks has not been established in the south, to the west of the Las Aradas fault (see relevant published 1:100000 geological maps).

The apparent absence of the Alao-Paute division in the south is problematical but assuming that these rocks were originally present in this area then one is forced to conclude either that their presence has failed to be recognised, or, alternatively, that they were subsequently destroyed/removed by tectonic processes which have affected this part of the then Ecuadorian continental margin.

2.5 Regional conclusions

Figure 3 shows two schematic geological sections across the Cordillera Real across the zones of recent studies. Although both sections will require revision in the light of future studies, they illustrate the important advances made particularly over the complex Central belt, not touched upon in Appendix 8.

In both sections rocks of the Western (collision) belt (see 2.2.12) are shown in tectonic contact with the Central belt along the Baños front. Once again (see Litherland, 1987) we have to report that the nature of the Baños front is "not fully understood": i.e. it is not clear if this is a fundamental line separating rocks of differing ages in any collision model. Figure 12a, as drawn, is remarkably similar to Alpine collision models (e.g. Dewey et al., 1986) but if this model were applied it would necessitate the underplating of the South American continent below the Chaucha-Arenillas plate (Appendix 8), contrary to the Cenozoic Andean continental margin subduction system, and such a model would be unable to account for the subduction-related sub-Andean Jurassic calc-alkaline batholith chain.

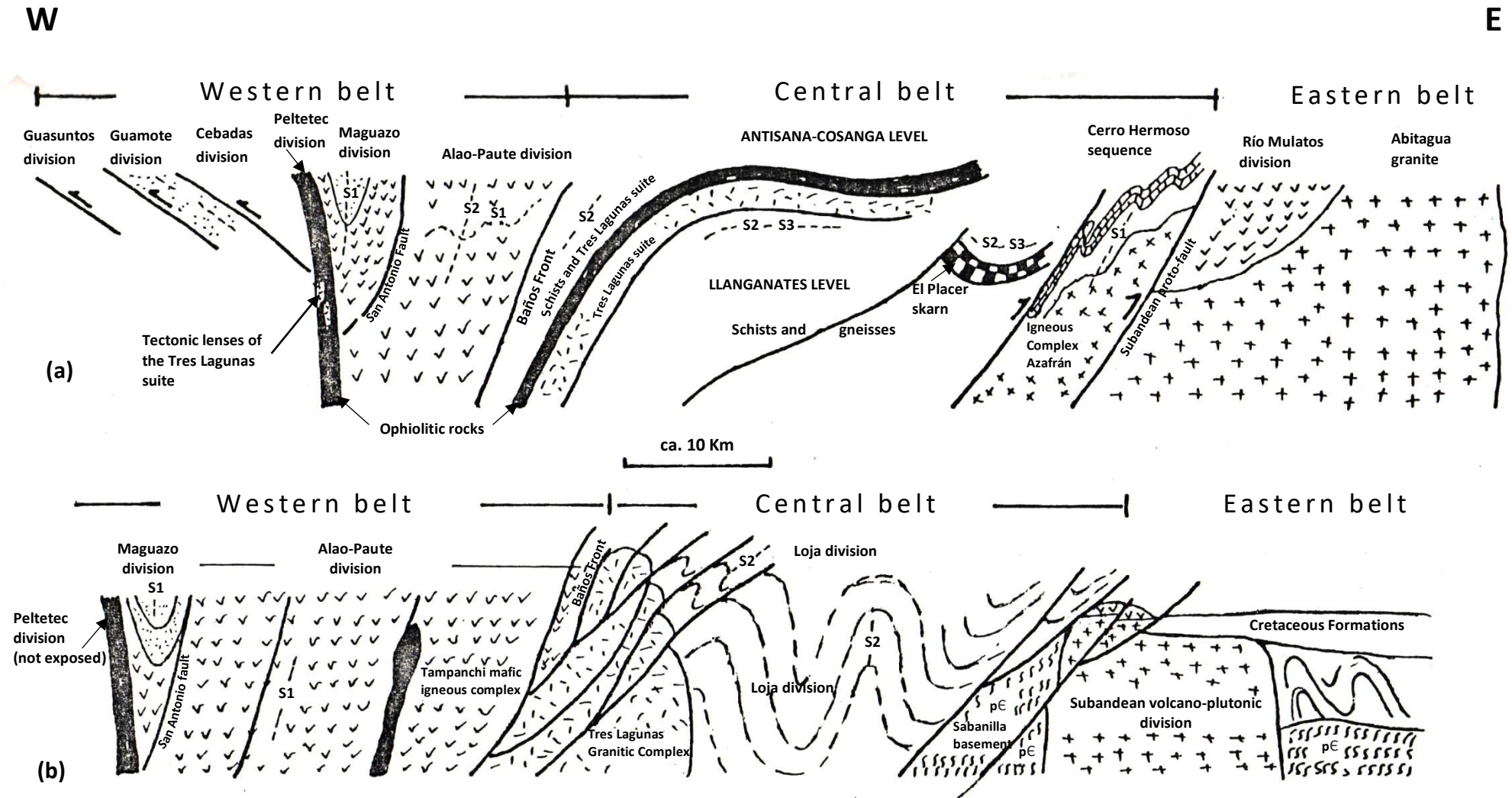


Figure 3. Schematic sections across the Cordillera Real metamorphic complex: (a) across the north of Map 1 and across Map 5 (pre-Cretaceous section); (b) across the south of Map 1 and across Map 10 (present-day section). S1, S2, etc. indicate relative ages of tectonic foliations.

At the moment there are too many unknowns, e.g., the overall direction of tectonic transport of Central belt thrusts and the provenance of Central belt ophiolites, to indicate relative underplating and whether collision was essentially one-stage or multistage. But collision there was, as illustrated by the Western belt Peltetec suture bordered east and west by thrust belts and a chain of collision granites to the east.

Clearly more geochronological and, if practical, palaeontological studies are required to establish ages of the (meta)sedimentary rocks and of the subduction- and collision-related processes: the metamorphic and plutonic events. One 'attractive' theory would comprise two subduction belts forming the Alao-Paute island arc and the sub-Andean continental arc. The marine sediments related to the latter, probable of Jurassic- Triassic age, could be linked to the Santiago Formation of the Oriente.

With regard to the Andean terrane reconstruction (Appendix 8), the recent studies have shown the extension of the Tres Lagunas collision granites to the east of the Aradas fault in the south of the Cordillera Real. It is thus logical to run the Baños front and the Peltetec (collision) suture down this same fault into Peru, rather than into Ráspas, as suggested in Appendix 8. Indeed, the Peltetec *mélange* contains tectonic slices of the Tres Lagunas granites. It is thus possible that the east-trending Ráspas suture of the Huancabamba Deflection was itself part of a much larger Chaucha-Arenillas-Tahuín-Amatope continental terrane prior to the Peltetec collision, or, that the Ráspas suture is the result of restricted opening of an oceanic basin following the Peltetec collision. There are thus many hypotheses to account for the Huancabamba Deflection.

3. MINERAL OCCURRENCES AND GEOCHEMICAL ANOMALIES

As in Litherland (1987) the mineral groupings follow those of the Mining Journal. Only mineral occurrences and geochemical anomalies found by the Project, or in Project-related studies, over the period in question, are noted here. These are integrated with previous Project information and extra-Project information under Chapter 4.

3.1 Precious metals

3.1.1 Gold

Electrum (gold-silver alloy) in pink arsenopyrite is present in some heavy mineral samples from the Río Mulatos (Appendix 4). A yellow metal is also reported in all samples.

Serpentinites and associated rocks from the Peltetec division, and serpentinites from the Central belt, show gold values ranging up to 1.6 ppm (Appendix 1).

0.3 ppm Au was recorded from a mineralised sample from the old workings at Cerro Hermoso (Appendix 1).

Gold was panned or was seen being panned in many rivers in the southern sector. Old gold workings were also noted. These localities are indicated on Map 10 and on the relevant commission maps (Maps 11-18). The occurrences fall into two main gold belts: the Collay-Shincata and the sub-Andean belts, which are discussed in section 4.4.

Gold values of 0.1 and 0.2 ppm were obtained from sulphide-rich zones along the Río Yacuambí (Map 15) related to faults and contact zones (Appendix 1).

3.1.2 Silver

The highest Ag value from the El Placer/Río Mulatos skarn rock samples is 5.8 ppm from a mineralised graphitic biotite-garnet schist (Appendices 1 and 5).

Levels of Ag in stream sediments reach 4 ppm in the upper reaches of Río Santa Bárbara (Appendix 2; Map 13) and 5 ppm north of Río Antisana (Appendix 2; Map 6).

3.2 Older major metals

3.2.1 Copper

Small Cu mineralization was noted in metalava blocks associated with blocks of serpentinite and epidote rock near the Río Cosanga headwaters.

Chalcopyrite/bornite is a common accessory mineral in the El Placer/Río Mulatos skarn samples (Appendix 5) and in heavy mineral samples (Appendix 4) along with tetrahedrite and cubanite/mackinawite. The highest Cu value from the rock samples is 1347 ppm from a tourmalinite.

In the Cerro Hermoso area, there is a small working in pyritised schists (Map 9) with associated quartz veins. Chalcopyrite was noted. Small Cu mineralization was also noted in narrow quartz-calcite veins cutting the carbonate sequence. Bornite was noted in weakly-mineralised garnet-contact rocks.

There is small malachite staining on blocks of the Río Alao pluton (Map 3).

Along the Río San Pedro (7416-97145) east of Cañar, there are small malachite stains in the Yunguilla lavas and sediments.

Small bornite/pyrite mineralization was noted near Quebrada Totora Yacu (7417-96849) along the main Río Paute road. The mineralization is associated with small quartz and calcite veins in cherts and turbidites of the Maguazo division and appears to be stratabound since it is found on both limbs of the main syncline (Map 1) at points approximately equidistant from the axial trace.

3.2.2 Lead and zinc

Sphalerite was noted in the El Placer/Río Mulatos skarn samples (Appendix 5) and Río Mulatos heavy minerals (Appendix 4). The highest Zn skarn rock value was 4279 ppm from an epidotised calc-schist.

Galena was noted in quartz vein blocks in the Río El Placer and in the Río Mulatos heavy minerals (Appendix 4).

Small galena mineralization was noted in marbles, close to volcanics, of the older metasedimentary division east of the Sabanilla basement (Map 18).

Smithsonite was tentatively identified in a block of greenish carbonate cavity-filling in the marbles of Cerro Hermoso.

Geochemical zinc anomalies of 451 and 490 ppm were detected from the Sigsig and Río Antisana sectors respectively (Appendix 2).

3.2.3 Tin

Cassiterite was tentatively identified in a heavy mineral sample from the Río Anatenorio (Appendix 4).

3.3 Steel industry metals

3.3.1 Chromite

Chromite is reported from Río Mulatos heavy mineral samples draining the Río Mulatos volcanic division (Appendix 4).

Cr levels in serpentines (Appendix 1) show levels (1000-3000 ppm) standard for worldwide ophiolite complexes (Hutchinson, 1983).

3.3.2 Cobalt

The highest Co value in the El Placer/Mulatos skarn rocks is 51 ppm from an ultramafic diopside “skarn” (Appendix 1).

3.3.3 Iron and pyrite mineralization

Up to 15% magnetite occurs in the El Placer skarn rocks (Appendices 4 and 5) and in the metalavas near the Río Cosanga headwaters, but no magnetite blocks have been noted in these sectors.

Small river blocks, up to 20 cm across, of magnetite rock were noted in seven areas of the Ona-Yacuambí traverse (Map 15), especially in the Río Cambena and downstream in the Río Yacuambí. These are associated with pyritic hornfels rocks.

Heavy sulphide (dominantly pyrite) mineralization was noted in the El Placer skarn rocks; in hornfels outcrops east of the union of the Ríos Ingenio and Yacuambí (Map 15); and as a 1 m wide fault zone near Quebrada Curishpe in the same sector.

There is a ca. 10 cm thick sulphide-rich zone at the base of the quartzite (No. 4 on Map 9), ca. 500 m SE of Laguna Walther Sauer in the area of Cerro Hermoso. This mineralization is associated with tourmaline and euhedral chloritoid and is probably of “stratabound” type, related to, or underlying, a thin conglomerate band.

3.3.4 Manganese

The 3.2% Mn in sample 267H (Appendix 1) probably relates to the presence of pink ?rhodochrosite in the rock but is of no economic significance.

3.3.5 Molybdenum

Grains of molybdenite have been noted in the Río Mulatos heavy minerals (Appendix 4). The highest Mo value in the El Placer/Río Mulatos skarn rocks is 113 ppm from an altered amphibolite.

3.3.6 Nickel

One sample from the Río Mulatos contains 5% pyrrhotite (Appendix 5).

Ni levels of 500-2000 ppm in the serpentinites (Appendix 1) are akin to worldwide ophiolite levels (Hutchinson, 1983).

3.3.7 Tungsten

The highest W value in the El Placer/Mulatos skarn rocks is 23 ppm from an impure siliceous marble.

3.4 Fuel minerals

3.4.1 Oil

As a result of carrying out routine field checks of the metamorphic rocks at the margin of the Tertiary Malacatus basin, outcrops were noted of chocolate-coloured mudstones, which when hammered gave off a distinctive odour of petroleum. Preliminary analyses of the samples indicate that they possess a total hydrocarbon yield (which includes any residual hydrocarbon content together with any immature organic material) of 60-80 kg/tonne.

The outcrops are located in Quebrada Santo Domingo where it is crossed by the “new” Malacatus-La Merced road. This road is not marked on the IGM ‘Gonzanamá’ topographic sheet, but it probably follows the line of the old camino de herradura and crosses the Quebrada Santo Domingo in grid square 88/38. According to the INEMIN geological sheet (Gonzanamá), the rocks are Miocene in age and probably belong to the San Cayetano Formation which also contains minor amounts of coal and gypsum.

There are rumours of oil seeps east of Palanda along the upper reaches of the Río Vergel. These have not been checked by the Project.

3.5 Chemical metals and minerals

3.5.1 Bismuth

Bismuth/bismuthinite was tentatively identified in heavy mineral samples from the Río Mulatos (Appendix 4).

3.5.2 Gypsum

This mineral is mined, locally, from the Tertiary rocks of the Malacatus basin.

3.5.3 Kaolin

Again, weathered, kaolinitic, microfeldspathic dykes, similar to those described in Litherland (1987), have been noted, but are not considered to have economic potential.

3.5.4 Phosphate rock

Analytical results (Appendix 1) of samples collected in the first year, and described in Litherland (1987), are disappointing. Clearly the pellet limestone from the Napo Formation is not a “phosphate rock” although geologists with experience of this unit had indicated the contrary.

3.6 Insulants and refractories

3.6.1 Asbestos

Blocks of green amphibole asbestos/talc up to 1 m across were noted associated with serpentinite blocks at the Río Cosanga headwaters (Map 6). Amphibole asbestos also occurs as an alteration product in the Tampanchi complex. Neither of these occurrences appears to be of economic interest.

3.6.2 Graphite

Although graphitic phyllites and schists are commonplace in the Cordillera Real, no high-grade zones of any thickness were noted.

3.6.3 Magnesite

This mineral occurs in serpentinite blocks (see 3.6.1), with no indications of economic concentrations.

3.6.4 Sillimanite minerals

Although all the sillimanite minerals (sillimanite, andalusite and kyanite) have been identified petrographically from contact or regionally-metamorphosed rocks during the year, no primary or secondary concentrations of economic interest have been noted.

3.7 Other industrial minerals, rocks and gemstones

3.7.1 Carbonate

Marble bands, possibly useful as a local source of lime, have been found along the Río Paute, ca. 250 m east of Quebrada Totorá Yacu (7406- 96849); along the Río Zula (Map 4); and west of Méndez, along the Río Negro (Map 11).

Other, previously-known, occurrences include the Napo Formation limestones; the marbles of the “older metasedimentary division” especially on the east bank of the Río Isimanchi, south of Isimanchi, and to the west of Valladolid on the Porvenir road (Map 10); and the marbles of Cerro Hermoso. These latter have been stratigraphically subdivided within a 500 m thick carbonate-dominant sequence (Map 9).

3.7.2 Feldspar

Feldspar-rich rocks, especially microfeldspathic dykes, have again been mapped, but it is unlikely if these have any economic potential.

3.7.3 Garnet

Although garnet is widespread in the metamorphic rocks, concentrations of over 50% only occur in the El Placer skarnfield and are not considered of economic interest. Crystals over 5 mm across also occur at Cerro Hermoso, but no material of gem quality was noted; all large crystals are inclusion-rich.

3.7.4 Mica

The small two-mica pegmatites in the Sabanilla basement complex north of Palanda (Map 10) are not considered of economic interest. Books are a maximum of 3 cm across.

3.7.5 Ornamental stone

The Tres Lagunas granites, especially samples from the least-deformed areas, e.g. Tres Lagunas and Santa Bárbara (Peggy Mine) plutons, would yield an attractive polished stone. The quartz is blue and, in addition, the K-feldspar is “smoky” grey and iridescent.

The El Placer skarn rocks are highly colourful with red/pink garnet, green epidote and pyroxene and black amphibole. They may be well-banded and contorted, and associated with similarly banded and ‘colourful’ marbles. Should an access road ever be cut into this area, their potential for ornamental stone should be examined.

Rocks of the more-accessible Tampanchi complex, particularly the coarse-grained, greenish hornblendites and associated pegmatitic gabbros (‘black granites’ of the stone trade) could be examined for ornamental stone potential.

3.7.6 Talc

Traces of talc have been noted associated with serpentinites and other ultramafic rocks, but have no economic interest.

3.7.7 Tourmaline

Small-scale tourmaline mineralization has been noted, and blocks of tourmalinite found (Appendix 5), but all comprise the black schorlitic variety and show no gemstone potential.

4. REGIONAL MINERAL POTENTIAL

4.1 Ophiolitic/ultramafic belts

4.1.1 Introduction

At the start of the Project only a few ophiolitic serpentinite rocks were known from Ecuador. These were the Saloya or San Juan complex east of Quito, the Pujilí serpentinite, the El Toro harzburgite of El Oro Province, and a small body at Río Palenque south of Pasaje (Baldock, 1982). Serpentinite blocks had been noted in rivers over or draining the Cordillera Real along the Papallacta-Baeza road (see 2.3.7), in the Río Guachalá near Cayambe (Sauer, 1965, and confirmed by the Project) and outcrops reported by Sauer in the Llanganates (see 2.3.7).

The present studies have identified two new ophiolite belts in the Cordillera Real, along the line of the Peltetec division and within the Central belt between the Papallacta and Pastaza rivers. It is possible that these belts represent fragments of a common oceanic crust. Studies over the Palenque serpentinite, south of Pasaje, indicate a major ophiolite mélange. Serpentinites have also been noted close to the Peruvian border (see 2.4.10). The main belts are discussed below in the light of regional mineral potential (Fig. 4), particularly precious metals.

4.1.2 The Palenque ophiolite (El Oro Province)

The relevant INEMIN 1:100000 sheet (Santa Rosa) indicates a small serpentinite body trending SW from the main quarry outcrop. The present compiler made a traverse from the quarry SE along the Río Palenque to the *estancia* (ca. 5 km) and then followed the stream draining from the south for a further 1.5 km. A geological sketch map is available which could be transferred to a topographic base.

The section undertaken represents ca. 5 km across the regional SW strike. Apart from the quarry serpentinite, at least three further, hill-forming, steeply-dipping serpentinite/harzburgite belts, up to 1 km thick, were mapped, intercalated, probably tectonically, with black and pale phyllites, cherts, pillow lava mélanges, and slices of hornblende/gneiss and sillimanite gneiss presumably derived from the continental block to the south (see Appendix 8), which was not reached.

Thus, the ophiolitic belt of Palenque is a thick sequence probably comprising a number of imbricate thrusts, and interpreted as the southern extension of the late Cretaceous/early Tertiary Pallatanga-Calacalí suture (Appendices 8 and 9). There are reports of soapstone and manganese in the area. One mining company geologist, following-up the Project information, has reported gold-bearing rivers and suggests the possibility that the Palenque ophiolite is the source of the Los Lilenes placer goldfield to the SW. The two serpentinite samples analysed for the Project show no gold (Appendix 1).

4.1.3 The Peltetec ophiolitic belt

This term can be applied to the rocks of the Peltetec and Maguazo divisions (Map 1) of the Western belt (see 2.2.4 and 2.2.5). The Maguazo division can be included since it contains oceanic-type rocks such as cherts. The igneous ophiolitic rocks: serpentinites, picrites, gabbros and spillitic basalts, are described under 2.2.4.

A serpentinite sample from the Huarguallá section gave 1 ppm gold (Litherland, 1987, Appendix 1); a serpentinite sample from Peltetec, 1.2 ppm Au (Appendix 1) and a gabbro from Peltetec 1.6 ppm Au. A silicified rock from the same locality gave 0.5 ppm Au.

There is visible small copper and zinc mineralization over the Peltetec-Huarguallá sector (Map 3) and a geochemical nickel/chromium anomaly from the main stream at Peltetec (Litherland, 1987).

A. Hirtz (personal communication) reports manganese ore in the Maguazo division near Peltetec and also anomalous vanadium levels in this sector. He also mentions reports of the discovery of chromite blocks in the hills near the Río Zula along the southward extension of the belt.

Small-scale copper mineralization of possible 'stratabound' type was noted in cherts and turbidites of the Maguazo division along the Río Paute (see 3.2.1).

The above mineral indices combined with the knowledge of the ophiolite setting suggests that this belt may be worthy of further prospection for precious metals (Au, Pt) and steel industry metals (Ni, Mn, Cr, V).

4.1.4 Ophiolitic rocks between the Papallacta and Pastaza rivers

These are described under 2.3.7. Most of the information is from river blocks, but one outcrop was noted. The serpentinites are thought to belong to major thrust sheets and are, in places, associated with variably epidotised mafic metalavas resembling rocks found in the El Placer skarnfield.

One block from the Río Mulatos gave a gold indication of 0.1 ppm whilst samples from the Río Mayo and the Río Antisana outcrop give 0.2 ppm Au (Appendix 1); but the (thrust) belt is still too poorly defined for any statement on mineral potential.

Sauer (1965, p. 30) reports up to 1.5% Ni from the serpentinites of the Río Mulatos (see 2.3.7).

4.1.5 The Tampanchi mafic igneous complex

As reported under 2.2.7, this unit is a reinterpretation of rocks described as "amphibolites" on the INEMIN Cañar geological sheet. The unit comprises mainly clinopyroxenites and hornblendites with minor gabbros, pegmatitic in places, and small late diorites. Recent private sector information indicates the presence of a dunite phase.

The presence of cumulate textures in the clinopyroxenite suggests that the Tampanchi complex is a layered mafic igneous complex, probably the first identified in Ecuador, formed by crystal-settling under gravity, probably from basaltic magmas from the mantle.

On a worldwide basis such bodies are important sites for metal ore prospection. The Precambrian Bushveld Complex of South Africa, for example, is the largest and greatest repository of metals in the world. It is mined for platinum group metals and gold, nickel, copper, chromite, vanadium pentoxide, magnetite, magnesite, fluorite, tin, and andalusite (Von Gruenewaldt, 1977).

Whilst the Tampanchi Complex is clearly not another Bushveld in terms of size or age and is presumably of a different setting, being emplaced into a presumed island arc sequence (Alao-Paute division) rather than stable Precambrian continental crust, there is the possibility that similar ore concentration processes were operative due to gravity settling, and it is this fact which makes Tampanchi a mineral prospection target.

Navarro (1986, Vol. III) reports gold and platinum concessions in the Pindilig area. Once the project reinterpretation of Tampanchi became known, a mining company began prospection and there are reports of gold and platinum in rivers draining the Tampanchi Complex.

At Bushveld such precious metals are located in the Merensky Reef, a late orthopyroxene-chromite pegmatoid containing post-cumular feldspar and clinopyroxene with local olivine-rich and quartz-rich facies. The precious metals are associated with base metal sulphides and have a clear preference for occurrence at the contact of the base metal sulphides with the silicate-oxide gangue (Vermaak and Hendriks, 1976).

It will be interesting to follow the private sector mapping and mineral exploration over the Tampanchi complex, and see if the gold and platinum can be traced to source, and whether there are any economic concentrations of other metals.

It is possible that a Tampanchi-type body is present near Laguna Magtayán, from where hornblendite samples were collected for age dating (Kennerley, 1980). K-Ar dates which arrived prior to the final typing of this chapter (C. C. Rundle telexed communication) give an age of 42 Ma for the Pungalá pluton (2.2.10) which is a younger age than that of Magtayán (54-85 Ma) and indicates a Tertiary age for the “Macuchi event”. Thus, the Magtayán body is probably older and may be the northern extension of the Tampanchi complex (Map 1).

4.2 Skarn rocks and other calcsilicates

4.2.1 The El Placer skarnfield

Float blocks of skarn rocks were found in the Río Mulatos in 1986 and ascribed to a “Llanganates skarn gold belt” (Litherland, 1987). A field trip to find the skarn outcrops was successfully undertaken (see 2.3.6). The provenance of almost all the ‘mafic skarns’ found as blocks in the Ríos Mulatos, Tigre and Niágara Chico and Niágara Grande (Map 7) can be narrowed down, approximately, to the skarn area indicated on Map 5: the El Placer skarnfield.

The skarn sequence, or tectonic packet, shows sub-horizontal tectonic foliations. At the base there are thin marbles and a thick unit of biotite-porphyroblastic amphibolitic metalavas. This is followed by waterfall outcrops of skarn, Ca-metasomatised metalavas, marbles, schists, and metadiorites (Fig. 2). The section on Figure 2 is ca 150 m in vertical thickness of which a minimum ca 30 m belongs to the skarn association. Skarn blocks were noted in the stream at the end of the traverse.

The skarn process produced massive, dense hard rocks, and all the large boulders in the Río El Placer/Quebrada San Martin and in the adjacent forest are of this lithology. Some are the size of a single-storey house.

The skarn and associated rocks in the tectonic packet generally exhibit strong sulphide mineralization (Appendix 5) and some show magnetite concentrations. A wider variety of lithotypes were noted as float blocks (Appendix 5).

The skarn rocks are of epidote-pyroxene-garnet-amphibole-magnetite endoskarn-type, interpreted as derived from a mafic or andesitic lava protolith. They appear to conform to island-arc calcic magnetite skarn deposits (Einaudi et al., 1981) generally related to diorite intrusions into sequences of mafic or andesitic lavas, sediments and thin limestones. On a worldwide basis such deposits are renowned for the presence of magnetite ore bodies, but concentrations of metals such as copper, zinc, molybdenum, cobalt, nickel, gold and silver may also be present (Einaudi et al., 1981).

30 Samples from the El Placer outcrops and blocks from the Río El Placer and Río Mulatos were analysed (Appendix 1). All these samples are accompanied by petrographic descriptions (Appendix 5). These results, whilst showing a few interesting values for certain other metals, show the highest gold at 46 ppb and highest silver at 5.8 ppm. In no way do they reflect the analytical values of 2.6-15.2 ppm gold and 8-22 ppm silver quoted in Litherland (1987, Appendix 1) from a similar suite of float blocks from the Río Mulatos collected on the 1986 traverse. The 1986 powders were sent to Canada where the “high gold” values were confirmed, but when new cuts from the original rock samples No. 137 and 149 were analysed, the results were 78 and 40 ppb Au respectively. Thus, it is possible that the 1986 sample chips fortuitously contained the only grain of gold in the entire sample.

A little gold was found in heavy mineral concentrates in the upper Mulatos (Appendix 4) probably derived from the El Placer skarnfield. However, recent information indicates that the local Oriente tribe, the Alamas, pan gold downstream in the Río Yarapo tributary (Map 5) and do not proceed further up the river.

The methodology was correct: (a) identification of skarn blocks on a regional river traverse; (b) followed by encouraging gold analyses; and (c) a follow-up trip to trace the skarn blocks to outcrop with the hope of discovering a hard-rock gold mine. But things weren't to be.

Aside from the disappointing preliminary results, what remains is a mountain, Serranía Arenillas (Map 7), 3600 m high, the top 800 m of which comprises a flat thrust sheet packet and, where outcrops were examined between 2900 and 3050 m at least 30 m comprises calcic-magnetite-skarns and associated Ca-metasomatised lavas, whilst float blocks indicate more skarn at higher levels. Sphalerite, chalcopyrite and galena have been seen in the rocks. In terms of mineral potential such a skarnfield cannot be discarded based on the limited data available. It is interesting to note the comments by Williams (Appendix 5) regarding the presence of late silicification/carbonation in the rocks and the occurrence of adularia in such a late quartz vein showing a textural affinity with the opaque minerals. Such late quartz-adularia (low temperature K-felspar) veins carry gold at Nambija (see 4.4.2).

As reported in 2.3.6, skarn blocks have been noted north of the main El Placer outcrop. Based on the present tectonic model, the El Placer thrust sheet should be found at the highest topographic levels further north and not in the main river canyons.

4.2.2 Epidote rocks between the Papallacta and Pastaza rivers

These localities are described in 2.3.6. Strong epidotization of mafic igneous rocks occurs at the Río Blanco de Patate (E. Salazar, personal communications); at the western margin of the Azafrán complex of the Río Pastaza section; as blocks in the Río Quijos near Baeza; and in the Río Mulatos volcanic division along the sub-Andean front. Blocks of metalava and strongly epidotised magnetite-bearing metalavas occur with blocks of serpentinite near the Cosanga headwaters (Map 6). Suffice it to say that the epidote rocks are similar to those seen associated with the El Placer skarns, and it may be that one or more of these occurrences are genetically related to the El Placer skarnfield with the possibility of a regional skarn/ophiolite thrust packet.

4.2.3 Cerro Hermoso

This mountain, in the heart of the Llanganates, is associated with legendary wealth, either as mineral deposits or as the location of Atahualpa's treasure. However, studies carried out (Map 9) showed no indications of large mineral deposits.

The presence of andalusite and sillimanite in pelitic beds indicates the proximity of an igneous intrusion and thus the potential for calcic skarns: skarn that replaces limestones and consists largely of Fe-Ca silicates. However, the garnet-bearing rocks along the eastern fault-bounded margin of the calcareous series (see 2.3.5) are not thought to relate to this process, rather the contact metamorphism of calc-pelitic sediments; in which case they are not related to metasomatism and are not true skarns. This is indicated by the appearance of the garnet within the more pelitic bands of the dominantly marble sequence, i.e. controlled by composition, and the lack of evidence for wholesale replacement of the sequence.

The small copper mineralization in hydrothermal veins parallel to the regional cleavage may be related to igneous activity and a similar interpretation could be ascribed to the small cavity fillings with possible smithsonite.

The present study has shown that the rocks have suffered contact metamorphism presumably related to the adjacent Azafrán igneous complex. The contact metamorphic minerals appear to be 'syntectonic' vis-a-vis the regional cleavage and thus contacts between the Azafrán complex and the carbonate rocks should be controlled by the regional folding and faulting. It is thus possible that along a strike from the study area mineralized calcic skarns may be exposed.

4.3 Polymetallic Belts

4.3.1 The Altar-San Bartolomé polymetallic belt

This belt is defined by old mines and mineral showings of Ag-Cu-Zn-Pb type (usually with Au) and includes the "Baños front-related polymetallic belt" of Litherland (1987). Mineralization is either in the Alao-Paute (metavolcanic) division of the metamorphic complex, or related to younger Cenozoic volcanic/plutonic units. Based on present information the belt extends from Baños in the north, to San Bartolomé in the south, and, possibly, further south to Fierro Urcu (Map 10).

In the north, polymetallic mineralization is indicated close to the Baños front at Baños, Tungurahua and at the colonial silver mines of Altar-Condorazo-Cubillín (Litherland, 1987; Navarro 1985, Vol. II) and along the Alao-Palora watershed (Litherland, 1987). This mineralization occurs in both basement metamorphic rocks and in the overlying Altar volcanics of Pleistocene age (A. Hirtz, personal communication). West from the trace of the Baños front at the Alao/Palora watershed, in the Alao Valley, there are many polymetallic occurrences within the Alao-Paute greenstone metamorphic division (Project studies; A. Hirtz, personal communication; Navarro, 1986, Vol. III, p. 99).

Further south, polymetallic mineralization occurs at the mines of Pilzhum, San Bartolomé and Peggy and there are other polymetallic showings and geochemical anomalies.

Pilzhum mine (Spindler and Herrera, 1959) occurs within a N-S trending hill now believed to be composed of a porphyry stock (Merlyn et al., 1988) rather than Tarqui volcanics (Bristow et al., 1975). Immediately to the north, on the same trend, there is a small Tertiary sedimentary basin (Biblián Formation) overlying Yunguilla Formation rocks. This line can be tentatively traced northwards on imagery to join the San Antonio fault of the metamorphic basement (Map 1). Mineralisation at Pilzhum is of epithermal type with high Ag values (1500 g/t) along three subvertical vein systems, at 20°, 80° and between 45° and 70° (Merlyn et al., 1988).

East of Pilzhum, but within the same Alao-Paute division basement, Bristow et al. (1975) report Pb-Zn-Mo geochemical anomalies close to the Río Paute. Over the same sector the Project noted polymetallic mineralization and geochemical anomalies (Litherland, 1987, 3.2.1 and 3.2.2).

Further south, the San Bartolomé prospect is situated on a structural break between the Canar-Azuay sedimentary basin to the west and the meta- morphic rocks (Alao-Paute division) to the east, within a volcanic cover which is preserved as a capping across the dividing zone (UNDP, 1979). The mineralization of San Bartolomé is of hydrothermal polymetallic (Zn-Pb-Cu-Ag) type along fracture systems (Merlyn et al., 1988).

Peggy Mine (Map 10) is situated along the Baños front with polymetallic mineralization within both the basement Tres Lagunas granite suite and Cenozoic Tarqui Formation breccia pipes and volcanics (see 4.3.2).

Thus, the Altar-San Bartolomé polymetallic belt shows polymetallic mineralization within the Alao-Paute metavolcanic rocks, and overlying or intruding Cenozoic volcanic-subvolcanic rocks. Many of these minerals' occurrences can be spatially related to the older collision faults as follows:

- (a) **The Baños front:** mineralization lies along or close to this line at Baños, Tungurahua, Altar-Condorazo-Cubillín, Amaluza and Peggy, both within the metamorphic rocks and overlying volcanic units.
- (b) **The San Antonio fault:** divides the Maguazo and Alao Paute division of the metamorphic complex, and differing tectono-metamorphic domains (see 2.2.11). Along this fault, across the Alao Valley, there is a younger volcanic intrusion related to silicification of the country rocks. When this fault is traced south (Map 10) it follows the line of the mineralised intrusive of Pilzhum Mine.
- (c) **The San Bartolomé fault:** can probably be linked to an older basement structure (see Map 1).

Thus, a hypothesis can be proposed to account for many of the mineralization sites along the Altar-San Bartolomé belt, involving the concentration of metal sulphides along collision faults and the later scavenging of these by Cenozoic volcanic fluids along these faults or during their reactivation, resulting in their redeposition/concentration at higher levels. Figure 3 illustrates some of these faults in section.

4.3.2 The Tres Lagunas tin-tungsten belt

The recognition of the Tres Lagunas granite suite (see 2.4.3) is not only important from the point of view of the understanding of the regional geological evolution of the Cordillera Real, but also it is of economic interest. These plutons are 'S'-type granitoids and are thought to have been generated during a major collision episode. Elsewhere in the world such plutons are commonly associated with tin-tungsten deposits, e.g. Malaya/Indonesia, Cornwall (SW England).

Previous to this project, isolated occurrences of tin were known in the Cordillera Real, but their regional geological significance was not appreciated. To the west of Saraguro, panned concentrates, in particular from the Río Aguarnupa (see Río Pichanal on Map 10), contain both cassiterite and scheelite (UNDP, 1972). It is clear from the report that this river drains an inlier of the Tres Lagunas suite which is extensively exposed further east. Both the Río Yanchurca and the Río Negro which drain NW from the main Tres Lagunas pluton carry scheelite (UNDP, 1972).

Further north, around Peggy Mine, cassiterite has been found in panned concentrates, and geochemical Sn anomalies, especially to the north of Quebrada Reote, have been noted (C. Seller, personal communication). Tourmaline occurs in relatively undeformed blocks of granodiorite below the main Peggy Mine in the Río Santa Bárbara and small blocks of quartz-tourmaline pegmatite have also been noted.

According to De Coster (1986) the main ore minerals in the Peggy Mine area are chalcopyrite, pyrrhotite and arsenopyrite, with smaller quantities of pyrite and marcasite. The less-abundant ore minerals are stannite, sphalerite, native bismuth and bismuthite. The gangue minerals are quartz, tourmaline and carbonates.

It is interesting to note from the data presented by De Coster (1986) that the Peggy mineralization contains both high temperature and low temperature elements, and thus we suggest that the tourmaline-tin mineralization is related to the Santa Bárbara pluton (i.e. the Tres Lagunas suite) whereas the lower-temperature assemblage may represent mineralization of 'epithermal' type associated with the Plio-Pleistocene Tarqui Formation. Thus, at Peggy Mine, which is situated on the Baños front, with Alao-Paute division rocks to the west and Tres Lagunas meta-granites to the east, the mineralization sequence could be as follows:

- (a) Collision-related (?Jurassic) Sn-W-tourmaline mineralization along the Baños front related to the Tres Lagunas granite suite.
- (b) Followed by Tertiary (?Tarqui Formation) reactivation of the Baños front with Cu-Zn mineralization related to the Alao-Paute division and forming part of the Altar-San Bartolomé polymetallic belt (see 4.3.1).

To the east of Gima, tourmaline-bearing greisens have been found in the Tres Lagunas belt but analyses are not available at present. Panned concentrates collected from rivers draining the Tres Lagunas belt also await analyses for Sn/W. Quartz-tourmaline pegmatites are associated with the small pluton to the SW of the Malacatus basin (Map 10).

The Tres Lagunas-type blue quartz granites can be traced northwards (Fig. 4). There is a considerable width, ca. 5 km, east of the Baños front on the Licto-Huamboya traverse (Litherland, 1987, Map 9), and also occurrences between Baños and Papallacta (Map 5). With respect to possible Sn-W mineralization, there are unconfirmed reports of cassiterite-rich heavy mineral concentrates “from the Llanganates”, and it is interesting to note that cassiterite was tentatively identified from a heavy mineral sample from the Río Anatenorio (Appendix 4) which drains the granitic orthogneiss belt of this sector.

4.4 Gold Belts

4.4.1 The Collay-Shincata gold belt

This belt is located along the western part of the Cordillera Real and extends for a distance of ca. 90 km from the Río Collay in the north to the Río Shincata/Río Betas in the south (Fig. 4). The width of the belt is variable, but is roughly in the order of 10 km across. It includes many of the historically-famous alluvial gold mining areas of the Cordillera Real and the area continues to be worked extensively at the present day.

Operations within the zone are all alluvial and generally small-scale, but, in the Río Collay for example, locally-organised groups/co-operatives may ‘employ’ up to 30-40 people. In most instances it appears that gold is panned from alluvial deposits in the main rivers and therefore mining operation are markedly seasonal. Since within the Cordillera the rivers tend to be deeply incised, large areas of alluvium are not present and water courses are often temporarily diverted or ‘canalised’ to allow access to the deep alluvial levels. The use of water pumps and “longtoms” is common in the larger operations.

The Collay-Shincata belt forms a well-defined zone of gold mineralization which is spatially closely associated with the Baños front and its projected extension to the south (see Au indications on Map 10). Although the Baños front is generally poorly exposed, particularly in the south where it is buried beneath an extensive cover of predominantly Plio-Pleistocene volcanics of the Tarqui Formation, to the east of Sigsig it can be seen to consist of a complex tectonic zone mainly of mylonitic rocks. In the west it includes a ca. 1 km strip of mylonitised metavolcanic and metasedimentary rocks which belong to the Alao-Paute division (Map 10). East of the Baños front there is a 5 km wide belt consisting of augen gneisses, phyllonites, biotite gneisses and siliceous quartz-feldspathic gneisses all of which represent variably deformed plutonic rocks of the Tres Lagunas suite. Further east siliceous semi-schists and semipelitic rocks of the Loja division are exposed.

In total the zone of mylonitic rocks associated with the Baños front is approximately 7 km across. They are Andean-trending with a consistent moderate to steep, westerly-dipping, tectonic foliation. In the east, however, the tectonic foliation in the Loja division is gentle to flat, but at present the precise structural relationship between the two tectonic regimes is not known.

In addition to the 'metamorphic basement' described above, the Baños front is also characterised by the presence of numerous post-tectonic minor intrusions. High-level, sub-volcanic intrusions, which in some cases include tuffaceous breccia pipes, are common. Some of the larger hornblende and biotite-bearing quartz-feldspar porphyries are shown in Map 10 but many of the smaller bodies remain unmapped. The ages of these various intrusive/subvolcanic bodies are not known, but they are generally assigned to the Plio-Pleistocene Tarqui Formation, the sub-aerial products of which blanket much of the area.

In spite of the widespread occurrence of gold in the Collay-Shincata belt, its primary source or sources remains unknown. Gold in quartz veins has been reported by local inhabitants from the western margin of the Loja division and from within the mylonite belt. Gold also occurs together with quartz. Although future, more detailed, studies in this area should resolve the source problem, it is thought that the gold mineralization relates to the Baños front and related mylonite belt. Since this structure has had a long and complex history, then it is probable that the associated gold mineralization is a multistage process and not restricted to a single host rock or environment. The heavily-silicified zones within and along the margin of the orthogneiss and the younger intrusions together with their contact zones would appear to represent priority exploration targets.

4.4.2 The sub-Andean gold belt

Along the Eastern belt sub-Andean zone in the south of the Cordillera Real, many rivers carry gold, and small-scale mining operations are common; but like the Collay-Shincata belt, the primary source of the gold is often unknown. However, geographically, there appears to be a close spatial relationship between the sub-Andean volcano-plutonic belt and the occurrence of alluvial gold (Map 10). This association is further emphasized if one considers the location of the few primary gold sources known from the area.

The hard rock gold mining areas of Nambija and Guaysimi lie east of Zamora (Map 10). Nambija was "rediscovered" in 1980 and became the site of the 'gold rush' which continues unabated to the present day. Geologically, there is little reliable information available about these areas, and thus the age of mineralization, geological setting and classification remain uncertain.

The Nambija gold area includes the Campanilla and Campana sectors located approximately 1 km and 2.5 km to the north, and Guaysimi, ca. 4 km to the SE. All these mines are spatially related to the Zamora Batholith (Map 10). A recent summary of available geological information, which includes new petrographic data (Salazar, 1988), indicates that these areas of primary gold are located within a belt of sediments, including volcanics, which has been “immersed” in the Zamora batholith and which has undergone both contact metamorphism and metasomatism. The age of this volcano-sedimentary “roof pendant” is unknown but is generally considered to belong to the Lower Jurassic Santiago Formation (Tschopp, 1953), or possibly the Macuma Formation of Upper Carboniferous age (Bristow and Hoffstetter, 1977). In a small stream which drains east of Guaysimi Mine there are outcrops of a characteristic porphyritic hornblende tonalite. River blocks of this lithotype are also common in Guaysimi Village, and a sample from one such block gave a K-Ar hornblende age of 151 ± 5 Ma (Litherland, 1987). Although the relations (if any) between this intrusion and the gold mineralization is not known, its Jurassic age indicates that it is part of the regional Zamora batholith.

Calc-silicates are the dominant lithology at both Nambija and Guaysimi mines and these typically comprise garnet-rich rocks of grandite (andradite-grossularite) garnet composition. A limited number of EMP analyses on these garnets showed a variation from $\text{Ad}_{70}\text{Gr}_{29}$ to $\text{Ad}_{45}\text{Gr}_{52}$ in andradite-grossularite proportions, with growth zoning in the direction of higher Ad contents (Beddoe-Stephens: in Litherland, 1987, Appendix 3). In addition to garnet, K-feldspar (usually altered, but when fresh, EMP studies indicate it to be virtually pure), quartz, calcite and epidote and minor amounts of chlorite and iron oxides are present. Pyrite is common and vesuvianite may be dominant in some samples (Salazar, 1988). According to Beddoe-Stephens (Litherland, 1987, Appendix 3) the gold is later than garnet (see also Salazar, 1988) but appears to be contemporaneous with the quartz-calcite-K-feldspar infillings.

Preliminary fluid inclusions data (Appendix 7) from Nambija and Guaysimi give homogenisation temperatures of 150-210°C with salinities (weight % NaCl equivalents) varying between 2-25%. All the inclusions were two-phase gas/liquid types. Despite the relatively high salinities, determined from freezing temperatures, recorded in some inclusions, the homogenisation temperatures are typically in the epithermal range and are somewhat lower than those normally recorded from skarns. Equally, as noted in Appendix 3, the garnets are devoid of fluid inclusions which could indicate a relatively dry environment of garnet crystallisation, i.e. a contact metamorphic ‘skarn’ of Einaudi et al. (1981), related to the intrusion of the Zamora batholith. The later, low-temperature, epithermal gold mineralization may therefore not necessarily relate to the main Zamora batholith but to a younger event. In this context it is of interest to note that Salazar (1988) reports quartzites and feldspar porphyritic lavas over the area. These lavas may be altered to form albite-epidote-quartz assemblages and are also associated with chloritised and epidotised volcanic breccias and felsic lavas. These volcanics show no evidence of contact metamorphism (Salazar, 1988) and could thus be younger than the main intrusive phase. If this is the case then the possibility that these volcanics relate to the epithermal gold mineralization should be investigated.

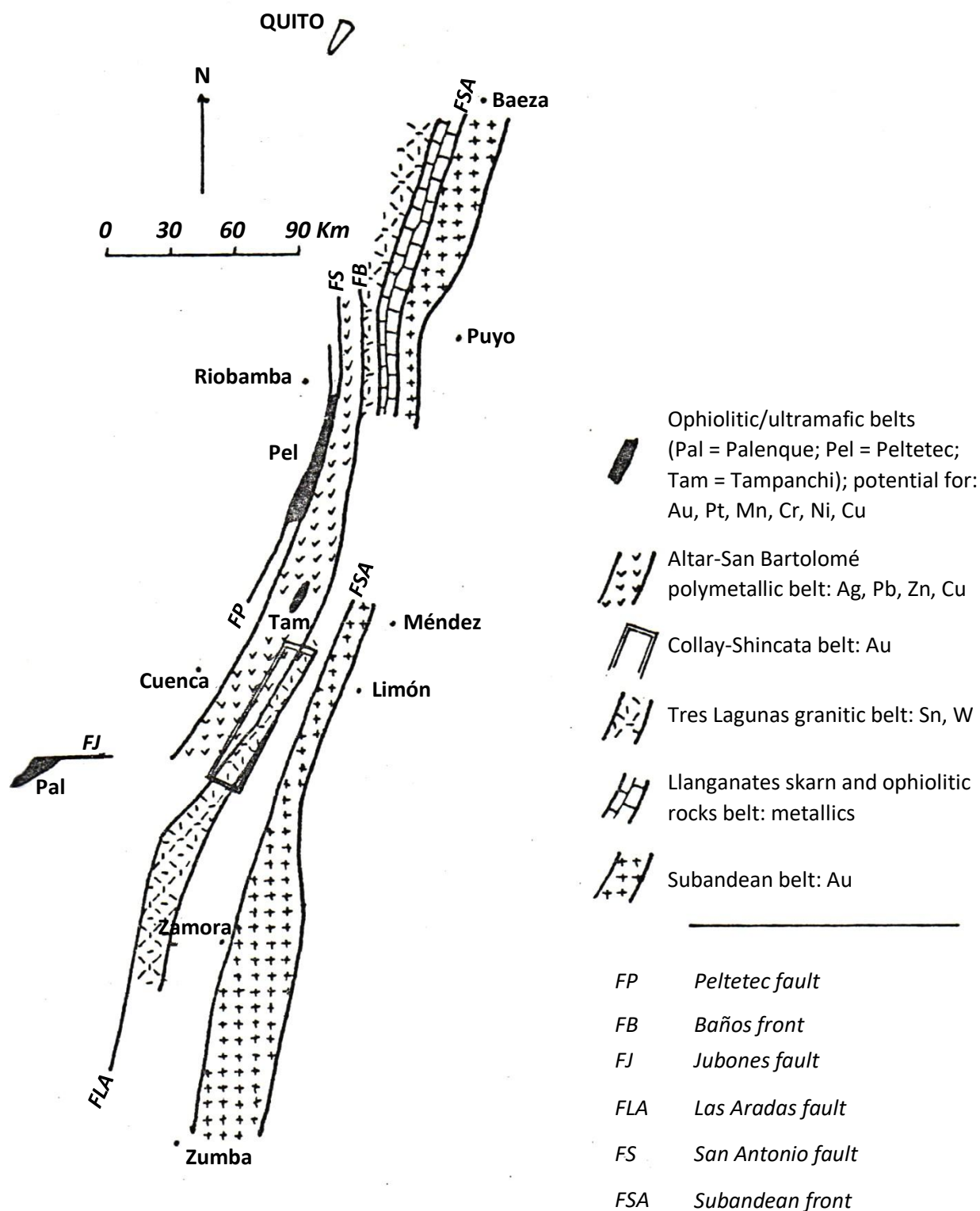


Figure 4. Mineral belts over the 1987-1988 Project study areas

Elsewhere in the southern sub-Andean gold belt, data on primary gold occurrences is more scanty. However, in the south, close to the Peruvian border, free gold and auriferous pyrite occurs in irregular zones of alteration within andesitic volcanics (Ing. N. Baez, personal communications), over an area where the volcanics are spatially associated with the Río Mayo batholith (Map 10). Further east, along the Peruvian border, these andesites are unconformably overlain by sandstones believed to belong to the Cretaceous Hollín Formation, which suggests that the andesites are of pre-Upper Cretaceous age and thus may belong to the Jurassic volcano-plutonic belt.

North of Nambija, volcanic/sub-volcanic rocks dominate the sub-Andean zone of the Eastern belt (2.4.7) and although gold is still common, no primary sources are known. Our present assumption is, however, that this gold is derived from the sub-Andean volcano-plutonic division but this hypothesis requires field checking. Only minor gold values (Appendix 1) have been detected in samples from silicified hornfelses and pyrite-rich contact zones.

Even further north, in the area of Map 5, gold is worked from many rivers, e.g. Napo, Jatunyacu, Verdeyacu, which drain the Abitagua batholith, the associated Río Mulatos volcanic division and the metamorphic complex of the Central belt. Since the Abitagua batholith and Río Mulatos division are correlated with the sub-Andean volcano-plutonic division further south, it is possible that a proportion of this alluvial gold is derived from epithermal-type deposits in this volcano-plutonic association, though this has not been indicated nor proven. However, in support of this hypothesis the following can be cited:

- (a) That the field evidence along the Río Mulatos suggests that the Abitagua Granite intrudes the Río Mulatos volcanic division, thus providing a mechanism for epithermal gold mineralization.
- (b) That the catchment areas of the gold-bearing Pano, Tena and Yorapo rivers are essentially restricted to the volcanic or plutonic divisions.

With respect to the gold-input from the Central belt metamorphic complex and its importance as a source of the placer gold in the Oriente of this sector, minor gold is present in streams draining the El Placer skarnfield (see 4.2.1). In the Río Chalupas, a local prospector has worked gold from the debris of a 20 m thick “quartz vein” along the river near the area of study (Map 5). Petrological studies showed this ‘quartz vein’ to be a post-tectonic microfeldspathic intrusion with a sulphide- rich pegmatitic contact zone against the host greenschists. The rock is compositionally similar to the ?late-stage Azafrán quartz-monzonite dated at 120 Ma (2.3.9) and samples of petrographically-similar rocks were collected at different sites along the Río Chalupas.

A great deal of work is required in order to fully understand the sub-Andean gold belt. At present the volcanic-plutonic division along the Eastern belt can be demonstrated to carry epithermal gold mineralization and this is likely to be an important source, and possibly the main source, of alluvial gold along the sub-Andean gold belt.

5. CONCLUSIONS

5.1 The recognition of regional mineral belts

The regional mineral belts found or delimited by the Project over the Cordillera Real and El Oro Province, described in this chapter, and depicted on Figure 4.

The recognition of these mineral belts illustrates the advances made since the first Annual Report (Litherland, 1987) in the field of regional mineral potential. It also illustrates only too clearly that knowledge of the geology and the application of plate tectonic models is a pre-requisite for understanding the geological setting and distribution of mineral occurrences and the prediction of their extensions for the benefit of future mineral exploration programmes. With respect to these comments the following remarks can be made for each belt:

- (a) **The Palenque ophiolite belt (El Oro Province)** is the logical extension of the Calacalí-Pallatanga suture recognise as far south as the Jubones fault by Megard and Lebrat (1987) (see Appendices 8 and 9). Both Megard and Lebrat (1987) and Feininger (1987) considered the Jubones fault as an important suture, but the recognition of the ca. 5 km wide Palenque ophiolite section rules out this hypothesis and opens up a large area for mineral exploration south of the Jubones fault.
- (b) **The Peltetec ophiolitic belt** was noted in Litherland (1987) at Alao and Huarguallá. The extension of this belt north to Penipe and south to the Río Zula, to the actual outcrops, was predicted by following the Peltetec fault on imagery. Thus Map 1 shows the precise zones for mineral exploration of ophiolite-type mineralization within the Peltetec and Maguazo divisions.
- (c) **The Altar-San Bartolomé belt** of known polymetallic mineralization has been found within or overlying the Alao-Paute (metavolcanic) division basement, and mineralization appears to relate to concentrations of metal sulphides along collision-related faults, or to later volcano-plutonic activity during Cenozoic reactivation of these same faults. Some of these faults, e.g. the Baños front and San Antonio fault, have now been identified and are recommended as sites for future mineral prospection.
- (d) Within the Altar-San Bartolomé belt the role of the **Tampanchi mafic igneous complex** is not clear. It may be the base of the Alao-Paute island arc, an ophiolite, or a later, post-tectonic body. It may be part of a large elongate structure or one of a series of smaller bodies extending north to Magtayán, and may not be a regional mineral belt in the sense of the other examples cited. Clearly, the Tampanchi complex requires detailed mapping and mineral exploration for “Bushveld-type” mineralization.
- (e) **The Collay-Shincata gold belt** has been defined as relating to the Baños front and/or later volcanic/plutonic activity along this collision structure. Further work is required to investigate the genesis of the gold before any prospection targets for hard rock gold can be recommended.

- (f) The recognition of the **Tres Lagunas S-type (collision)** granite suite and its extension throughout the bulk of the Cordillera Real is based on the Project's geological studies. Its (predictable) association with Sn-W mineralization at Saraguro now opens up a host of exploration areas.
- (g) The newly-discovered **Llanganates skarn/ophiolitic rocks** within and north of the Llanganates mountains may be interesting in terms of mineral potential. However, the tectonic setting cannot be considered as relating to steep geological contacts or steep faults. Instead, the outcrop pattern of these skarn/ophiolitic rocks appears to relate to subhorizontal thrust sheets; and this should be taken into account in any further mineral exploration. Thus, for example, the El Placer skarnfield occurs as a thrust sheet found at the highest topographic levels, 1000 m above the main canyon sections. North of the Río Mulatos any re-appearance of this skarnfield should be at similar mountain-top levels.
- (h) The hard rock gold occurrences of the Zamora batholith region and much of the placer gold of the sub-Andean and Oriente regions of Ecuador, can be linked directly or spatially to the sub-Andean volcano-plutonic division to form the **sub-Andean gold belt**. Indication are that this is an epithermal gold belt linked to the later stages of the Jurassic plutonic activity.

5.2 The significance of the mineral belts for the Ecuadorian mining industry

In terms of the future of the Ecuadorian Mining industry, the advances in the understanding of the geology and mineral potential of the Cordillera Real, as outlined in this report, and as illustrated on Figure 4, provide the following:

- (a) A growing database for investors: all serious mining companies prefer, and sometimes may require, a geological and mineral database to convince their respective boards of directors that investment risks are based on sound geological and mineral data. If capital is to be spent on a known mineral prospect the company geologists will require the details of the mineralization at the prospect itself and also the regional geological setting, i.e. he wants to know why mineralisation has occurred at that particular locality. We believe that the results of the Project are providing the support service for such capital risk investment.
- (b) Target areas for mineral prospection: the recent trend appears to be for mining companies to enter Ecuador, often in partnership with local groups, to work on a specific low-risk prospect or concession, generally involving gold. However, once established, they may wish to expand their operations in the form of mineral prospecting programmes over other areas. It is in this field where the mineral occurrences noted by the Project and the regional mineral belts and geological settings outlined on Figure 4, will be of great benefit both to the individual companies concerned and to the Ecuador mining industry in general.

5.3 Future programme and Project policy

Serious geological and mineral studies over the Cordillera Real are still in their infancy as illustrated by this progress report on the Project's 1987-1988 results. However, sufficient studies have been undertaken to be able to state categorically that the future rewards in terms of geological and mineral understanding will be greater over the remaining years of the Project. Things will begin to fall into place: the hypothesis of continental collision accompanied by large scale overthrusting, both so far unreported in the Andes, will be refined into a theory to fit the scientific data; new mineral occurrences will be found and these, along with previous occurrences and those made known to us by interested private sector companies, will be integrated into the complex geological history, thus defining the metallogenetic processes in space and time and redefining the mineral belts and target areas.

We regard continued field studies and the geochronological dating programme as the priorities for the future. With the geological/mineral experience already obtained, coupled with an open-minded approach to geological models, future geotraverse will be more rewarding, e.g. in the rapid identification of river float blocks with regional mineral potential such as ophiolites and skarns. Further studies will be carried out in 1988- 1989 over the areas of Maps 5 and 10 and work will also be undertaken across the Cordillera Real north of the Río Papallacta and between the Ríos Pastaza and Paute, in order to fill some of the gaps in the overall regional picture (Fig. 1).

Follow-up mineral programmes by the residential geological teams will only be justified where there are prospects of discovering outcrops of important mineral potential over less-accessible areas such as the quest for the El Placer skarnfield. It is clear that mineral potential targets over accessible areas, e.g. the Tampanchi complex and Palenque ophiolite, are quickly exploited by the private sector, even though no mineralization was noted by the Project teams during the initial reconnaissance. It is hoped that during 1988-1989 an ODA economic geologist will study the mineralization of the Altar-San Bartolomé, Collay-Shincata, Tres Lagunas and sub-Andean belts and reach specific and regional conclusions as to their respective metallogenesis. With regard to the Tres Lagunas granite suite, and the possibility of an associated belt of Sn-W mineralization, a regional sampling programme along the Cordillera Real could probably not be justified by a mining company owing to the present market prices. However, localisation of such deposits would constitute an important strategic resource for Ecuador, and thus INEMIN should consider undertaking such a programme.

We appreciate the help with analyses provided by the private sector in this report and welcome any future collaboration always based on the understanding that any results will be reproduced in the relevant Annual Report. We also appeal to the representatives of the respective governments involved in the convenio, not just to maintain their interest in the Project, but also to lend a friendly ear to appeals for further input. We feel sure that this report will be a reassurance that the Project is providing "value for money".

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APPENDIX 1

Chemical rock analysis and sample data

English translation by Stalyn Paucar (2026)

Table 1. Samples analyses - INEMIN

ZONE	SAMPLE CODE	LITHOLOGY	P ₂ O ₅ (%)	Ti (%)	V (ppm)	Cr (ppm)	Mn (ppm)	FeO+Fe ₂ O ₃ (%)	Co (ppm)	Ni (ppm)	Cu (ppm)	Zn (ppm)	Ag (ppm)	Au (ppm)	Pb (ppm)
Cayambe	RB-1-G	Serpentinite		0.02	25	2100	245	6.52	102	1800	19	268	5	Nd	101
Baeza	RB-43-C	Serpentinite		0.07	33	3400	731	4.89	115	1600	6	137	2	Nd	106
	RB-43-D	Serpentinite		0.02	23	2200	735	4.73	103	1600	7	126	4	0.1	102
Peltetec	RB-59-A	Serpentinite		0.20	103	1200	733	10.56	134	517	12	98	4	1.2	134
	RB-59-B	Gabbro		0.26	84	681	609	3.85	95	190	24	86	3	1.6	160
	RB-59-D	Picrite		0.94	104	784	655	4.22	105	240	35	111	4	Nd	144
Río Mulatos	RB-136	Serpentinite		0.07	34	2500	683	5.38	117	2000	13	241	2	Nd	117
	RB-138	Phyllite, sericite-andalusite		0.48	65	901	419	2.29	73	201	6	793	2	Nd	148
	RB-140-A	Serpentinite		0.05	41	3000	799	5.07	132	1300	41	382	4	0.1	84
	RB-144-G	Serpentinite		0.12	46	2400	639	4.89	167	1700	57	233	2	Nd	132
	RB-145-G	Amphibole-biotite schist		2.87	155	144	803	5.22	167	88	553	571	4	Nd	120
	RB-154-B	Metadacite		1.72	101	27	734	3.89	49	31	12	160	3	Nd	129
	RB-159-A	Pellets limestone	0.11												
Huamboya	RB-71	Magnesian schist		1.09	92	577	611	3.83	79	264	28	80	3	Nd	119
Guarumales	FV-153	Calcsilicate		3.71	127	91	5200	4.46	79	62	9	145	5	Nd	159
Papallacta	RB-25-D	Granitoid	2.25												

Nd = not detected

DATA OF ANALYSED SAMPLES

RB-1-G: Pan-American Highway, 500 m upstream from the Guachalá River bridge, south of the town of Cayambe. Serpentinite block, probably derived from the Central Belt of the Cordillera Real.

RB-43-C; RB-43-D: Quijos River, 1.5 km ENE of Baeza (8445–99493). Serpentinite blocks.

RB-59-A: Pungalá-Alao road (7716-97946). Serpentinite block from the stream in the Peltetec division.

RB-59-B: Pungalá-Alao road (7716-97946), Gabbro block from the outcrop along the road, Peltetec division.

RB-59-D: Pungalá-Alao road (7716-97946). Picrite block from the stream, Peltetec division.

RB-136; RB-140-A; RB-144-G: Mulatos River (Map 7). Serpentinite blocks from the Central Belt.

RB-138: Mulatos River (Map 7). Low-grade sericite–andalusite rock block (contact rock).

RB-145-G: Mulatos River (Map 7). Schist block with amphibole and biotite.

RB-154-B: Mulatos River. Metadacite block with epidote.

RB-159-A: See Litherland (1987), Appendix 1.

RB-71: Near El Placer along the Alao–Huamboya route. Quartz–tremolite schist block with sulphides from the Central Belt.

FV-153: Block near Quebrada Ventanillas (7728–1466). Calc-silicate rock with garnet.

RB-25-D: See Litherland (1987), Appendix 1.

Table 2. INEMIN analyses for gold only, and for some samples, silver

ZONE	SAMPLE CODE	LITHOLOGY	Au (ppm)	Ag (ppm)
Alao Valley	RB-222-A	Silicified volcanic rock	Nd	
	RB-222-B	Silicified volcanic rock	Nd	
	RB-222-C	Silicified volcanic rock	0.1	
	RB-224	Silicified volcanic rock	Nd	
Peltetec	RB-225-A	Silicified mélange rock	Nd	
	RB-225-H	Silicified mélange rock	0.5	
Río Zula	RB-231-A	Silicified mélange rock	Nd	
Mina Pilzhum	RB-238-B	Silica vein	Nd	
Río Paute	RB-243-B	Silicified rock?	Nd	
Río Huarquallá	RB-250-B	Silicified volcanic rock	Nd	
Río Yacuambí	A-110	Silicified volcanic rock	0.2	
Río Cambana	A-112	Silicified intrusive rock with pyrite	Nd	
Quebrada Napurca	A-119	Felsite mineralised with sulphides	0.1	
Guadalupe	A-122	Intrusive contact rock with sulphides	Nd	
Río Tres Lagunas	A-125	Silicified rock with a quartz veinlet	Nd	
Penipe	RB-209-B	Hornblendite	Nd	Nd
	RB-209-E	Hornblendite	Nd	Nd
	RB-209-G	Serpentinite	Nd	Nd
Tampanchi	RB-247-A	Hornblende/asbestos rock	Nd	Nd
Palenque (El Oro)	FV-285-Q	Serpentinite	Nd	Nd
	FV-285	Serpentinite	Nd	
Tahuín (El Oro)	FV-291-A	Serpentinite	Nd	Nd
Río Mayo	RB-296-B	Serpentinite	0.2	
Cerro Hermoso	RB-313-A	Garnet-bearing rock	Nd	
	RB-326-C	Schist with pyrite	0.3	
Río Antisana	RB-342	Serpentinite	0.2	
Cabecera del Cosanga	RB-353-A'	Serpentinite	Nd	
	RB-353-E	Mafic metalava	Nd	
	RB-353-G	Epidote-bearing rock	Nd	
	RB-353-I	Mafic metalava	Nd	

Nd = not detected

DATA OF ANALYSED SAMPLES

RB-222-A; RB-222-B; RB-222-C: Alao Valley (7774-97930). Blocks of microvolcanic/silicified rock derived from the hillside, from the San Antonio fault zone.

RB-224: Alao Valley (7768-97916). Outcrop of silicified greenschist from the San Antonio fault zone.

RB-225-A; RB-225-H: Pungalá-Alao road (7716-97946). Blocks of silicified ophiolitic mélange from the stream, Peltetec division.

RB-231-A: Road along the Zula River, west of Totoras (7553-97495). Outcrop of silicified mélange, Peltetec division.

RB-238-B: Pilzhum Mine (7482-97072). Block of silica vein.

RB-243-B: Silicified rock?

RB-250-B: Tributary stream of Quebrada de Shaigua (7746-97857). Block of silicified rock, probably from the San Antonio fault zone.

A-110: Yacuambí-La Paz mule track, near Cambona Chico (3182-9594). Contact rock located within the Zamora Batholith, containing sulphide mineralisation, mainly pyrite.

A-112: Yacuambí-La Paz road (9508-3241). Hornfels with pyrite, from the contact with the Zamora Batholith.

A-119: La Paz-Guadalupe road (3714-8584). Block of intrusive rock (felsite) mineralised with sulphides (pyrite) from the Zamora Batholith.

A-122: La Paz-Guadalupe road (3445-7744). Intrusive rock mineralised with sulphides (pyrite) from the Zamora Batholith.

A-125: Camino Principal-Tres Lagunas; cerca de Laguna Grande. Roca silicificada.

RB-209-B: Camino Penipe-Río Blanco (7750-98253). Hornblendita de la división Peltetec.

RB-209-E: Penipe-Río Blanco road (7750-98253). Hornblendite from the Peltetec division.

RB-209-G: Penipe-Río Blanco road (7750-98253). Serpentinite from the Peltetec division.

RB-247-A: Taday-Guaraynag road (7618-97082). Hornblende-asbestos rock from the Tampanchi Complex.

FV-285-Q: Palenque River, south of Pasaje, ca. 2 km SE of the quarry. Serpentinite outcrop.

FV-285: Palenque River, south of Pasaje. Serpentinite from the quarry.

FV-291-A: Quarry, c. 2 km north of Tahuín. Serpentinite from the El Toro body.

RB-296-B: Quebrada de los Incas, at its confluence with the Mayo River (7901-98582). Serpentinite block.

RB-313-A: Cerro Hermoso (8016-98638). Outcrop sample of garnet-bearing rock with sulphides.

RB-326-C: Cerro Hermoso (8012-98643). Schist sample with sulphides from an old working site.

RB-342: North of the Antisana River (8159-99322). Sample from serpentinite outcrops.

RB-353-A': North of the Antisana River (8195-99306). Serpentinite block.

RB-353-E: North of the Antisana River (8195-99306). Mineralised mafic metalava block.

RB-353-G: North of the Antisana River (8195-99306). Mineralised epidote-bearing rock block.

RB-353-I: North of the Antisana River (8195-99306). Mineralised mafic metalava block.

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ACME ANALYTICAL LABORATORIES LTD.

852 E. HASTINGS ST. VANCOUVER B. C. V6A 186

PHONE (604)253-3158

FAX (604)253-1716

GEOCHEMICAL ANALYSIS CERTIFICATE

ICP - 0.500 GRAM SAMPLE IS DIGESTED WITH 3ML 3-1-2 HCL-HNO3-H2O AT 95 DEC. C FOR ONE HOUR AND IS DILUTED TO 10 ML WITH WATER
THIS LEACH IS PARTIAL FOR Mn Fe Ca P La Cr Mg Ba Ti B W AND LIMITED FOR Na K AND Al. Au DETECTION LIMIT BY ICP IS 3 PPM.

- SAMPLE TYPE: Rock Chips AU** ANALYSIS BY FA+AA FROM 20 GM SAMPLE

DATE RECEIVED: OCT 23 1987

DATE REPORT MAILED: OCT 26 1987

ASSAYER: DEAN TOYE, CERTIFIED B.C. ASSAYER

B. P. MINERALS INTERNATIONAL File # 87-4900

SAMPLE	Mo (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ag (ppm)	Ni (ppm)	Co (ppm)	Mn (ppm)	Fe (%)	As (ppm)	U (ppm)	Th (ppm)	Sr (ppm)	Cd (ppm)	Sb (ppm)	Bi (ppm)	V (ppm)	Ca (%)	P (%)	La (ppm)	Cr (ppm)	Mg (%)	Ba (ppm)	Ti (%)	B (ppm)	Al (%)	Na (%)	K (%)	W (ppm)	Au (ppm)	Au** (ppb)
RB-261	1	8	65	117	0.4	483	20	309	1.68	82	5	1	1	1	6	8	9	0.21	0.004	2	814	11.28	3	0.01	4	0.28	0.01	0.01	1	ND	10
RB-265	4	24	7	73	0.1	27	25	155	16.64	129	5	5	3	2	2	2	28	0.25	0.051	2	13	0.30	40	0.13	6	0.79	0.01	0.53	1	ND	6
RB-266	1	39	25	4279	0.1	30	6	525	2.42	22	5	2	42	22	5	2	33	0.97	0.104	5	19	0.07	89	0.12	2	0.43	0.01	0.02	1	ND	1
RB-267-A	113	244	261	112	2.9	127	46	2432	8.19	29	5	2	22	1	4	2	28	3.06	0.331	6	19	0.08	21	0.06	2	0.67	0.05	0.06	1	ND	1
RB-267-H	1	6	17	29	0.1	90	37	32581	0.9	182	5	1	13	3	2	2	1	0.75	0.058	2	12	0.19	5	0.01	7	0.06	0.01	0.01	1	ND	27
RB-268-B	4	213	20	125	0.3	30	13	1614	6.74	4	5	15	189	1	4	2	76	17.32	0.301	23	30	0.62	9	0.01	2	1.32	0.01	0.01	1	ND	1
RB-269-B	20	1347	9	464	4.9	16	9	2190	1.33	10	5	1	8	2	2	2	11	0.32	0.027	2	7	0.39	6	0.01	184	0.50	0.02	0.02	1	ND	30
RB-271-B	1	100	9	97	0.1	5	9	472	6.5	4	5	2	78	1	3	2	48	0.71	0.001	10	8	0.88	98	0.08	11	2.65	0.09	0.36	1	ND	1
RB-273	1	29	8	66	0.2	52	20	540	3.24	7	5	2	25	1	3	2	56	0.82	0.029	2	80	1.99	110	0.32	2	2.09	0.05	0.37	1	ND	5
RB-274	1	626	12	36	0.8	47	51	188	2.23	69	5	1	5	2	2	2	3	0.95	0.051	2	3	0.28	8	0.01	2	0.05	0.01	0.01	1	ND	1
RB-280	8	11	27	263	0.3	13	2	1307	1.86	2	5	1	108	1	2	2	35	20.35	0.027	4	12	3.46	8	0.02	5	0.13	0.01	0.02	1	ND	5
RB-281	8	27	2	17	0.1	20	15	966	8.09	14	5	1	16	1	2	2	60	7.63	0.053	2	14	0.07	10	0.05	7	0.26	0.01	0.02	1	ND	1
RB-285-A	29	10	3	15	0.2	9	2	2194	2.93	51	5	2	10	2	2	2	119	11.74	0.136	2	48	0.11	28	0.07	13	0.62	0.01	0.01	3	ND	1
RB-285-B	2	434	4	91	0.1	13	2	1787	4.46	72	5	1	3	3	2	2	79	5.2	0.074	2	28	0.05	19	0.05	7	0.46	0.01	0.01	15	ND	1
RB-285-C	24	11	72	70	0.3	109	3	221	0.50	178	5	7	21	2	3	2	151	2.47	0.309	25	52	0.04	8	0.05	103	0.47	0.01	0.01	1	ND	1
RB-286-A	5	659	278	174	2.7	10	1	181	0.99	294	5	2	44	2	6	2	17	1.13	0.120	5	25	0.11	3	0.09	5	0.45	0.01	0.01	1	ND	46
RB-286-B	3	112	15	16	0.3	6	1	321	1.06	27	5	3	53	1	2	2	29	1.76	0.226	9	36	0.12	7	0.11	6	0.61	0.01	0.01	1	ND	1
RB-286-C	43	434	11	11	0.5	9	1	436	0.68	24	5	1	10	1	3	2	77	1.92	0.251	2	12	0.09	1	0.08	2	0.31	0.01	0.01	1	ND	1
RB-286-D	2	117	10	12	0.2	5	1	278	1.54	21	5	2	61	1	6	2	25	1.74	0.183	9	33	0.06	7	0.10	17	0.75	0.01	0.01	1	ND	2
RB-286-E	10	678	7	18	0.9	13	2	910	1.41	19	5	1	12	1	3	2	76	1.43	0.172	2	9	0.14	6	0.05	2	0.50	0.01	0.01	1	ND	1
RB-286-G	5	172	7	29	0.5	17	2	1569	8.02	22	5	3	9	1	2	2	127	5.98	0.123	2	66	0.04	14	0.07	7	0.61	0.01	0.01	4	ND	1
RB-287	9	45	8	13	0.2	14	1	1104	1.73	16	5	1	14	1	2	2	124	2.28	0.106	3	21	0.12	6	0.05	2	0.57	0.01	0.01	2	ND	1
RB-288-A	6	111	6	30	0.6	22	2	1748	2.23	42	5	1	61	1	6	2	28	13.84	0.069	6	22	0.11	8	0.01	8	0.28	0.01	0.01	23	ND	2
RB-288-B	4	8	3	108	0.3	47	4	1031	3.33	12	5	3	38	1	3	2	78	5.96	0.087	7	83	0.58	42	0.06	3	1.29	0.01	0.06	2	ND	1
RB-289	6	21	188	884	5.8	63	4	2692	4.61	19	5	4	149	4	5	2	181	13.93	0.092	22	109	0.71	10	0.05	2	1.49	0.01	0.01	1	ND	3
RB-290	1	14	2	40	0.3	2	2	159	0.58	7	5	1	43	1	3	2	17	0.96	0.089	2	5	0.11	28	0.18	7	0.41	0.05	0.03	1	ND	1
RB-291-A	10	15	41	201	0.5	63	2	1146	0.95	7	5	1	224	2	2	2	144	10.83	0.069	8	57	0.50	29	0.12	6	0.41	0.02	0.38	1	ND	2
RB-292-A	4	126	8	33	0.1	8	6	194	11.32	5	5	2	9	1	2	2	13	1.07	0.032	2	9	0.07	5	0.02	2	0.31	0.01	0.01	2	ND	1
RB-292-B	1	108	29	92	0.4	14	8	1277	3.27	37	5	1	99	2	4	2	25	2.80	0.060	3	7	0.36	17	0.15	4	1.16	0.01	0.01	1	ND	2
RB-293	1	39	18	40	0.2	4	8	217	2.10	31	5	1	6	1	2	2	11	0.19	0.036	2	4	0.17	78	0.10	8	0.38	0.04	0.13	2	ND	1
RB-294	1	16	4	61	0.1	7	13	464	2.09	42	5	1	62	1	2	2	26	0.75	0.047	2	7	0.06	11	0.20	2	0.38	0.05	0.01	1	ND	7
STD C/AU-R	19	59	37	131	7.5	69	28	1048	3.84	39	20	39	51	20	18	23	59	0.43	0.088	38	59	0.80	180	0.08	35	1.78	0.06	0.13	12	7	480

Skarns and associated rocks, Río Mulatos and Río El Placer. See Map 7, Figure 2 for locations and Appendix 5 for petrography.

Analysse sponsored by B.P. Minerals International

APPENDIX 2

Geochemical analysis of stream sediments

English translation by Stalyn Paucar (2026)

Cordillera Real Geological Research Project

INSTITUTO ECUATORIANO DE MINERÍA DEPARTAMENTO DE LABORATORIOS CHEMICAL ANALYSIS REPORT

LAB N°: 3671 DELIVERY: Ing. Iván Endara DATE: 87-07-21
N° of SAMPLES: Eight Jefe de Laboratorios
REQUESTED BY: Ing. F. Viteri RECEPTION: Ing. W. Santamaría DATE: 87-07-21
PROJECT: Cordillera Real Director de investigación geológica
ORIGIN: Azuay-Cañar; Sigsig-Chigüinda (see Litherland, 1987, Map 14)

DETERMINATIONS

SAMPLE CODE	As (ppm)
A-097	200
A-098	62
A-099	90
A-100	72
A-101	64
A-102	140
A-103	90
A-104	50

ASSAYED BY: Determinaciones Analíticas

MARIANA LÓPEZ
Jefe de Determinaciones Analíticas

INSTITUTO ECUATORIANO DE MINERÍA
DEPARTAMENTO DE LABORATORIOS
CHEMICAL ANALYSIS REPORT

LAB N°: 3735 DELIVERY: Ing. Iván Endara DATE: 88-03-02
N° of SAMPLES: Fifteen Jefe de Laboratorios
REQUESTED BY: Ing. F. Viteri RECEPTION: Ing. W. Santamaría DATE: 88-03-02
PROJECT: Cordillera Real Director de investigación geológica
ORIGIN: Sigsig-Principal; Sigsig – Santa Bárbara; Principal – Tres Lagunas; Oña – Tres Lagunas

DETERMINATIONS

SAMPLE CODE	Ag (ppm)
A-105	1
A-106	Nd
A-107	2
A-108	4
A-109	Nd
A-111	1
A-113	Nd
A-114	Nd
A-115	Nd
A-116	Nd
A-117	Nd
A-118	Nd
A-120	Nd
A-121	Nd
A-123	Nd

Nd = not detectable, less than 1 ppm Ag

ASSAYED BY: Determinaciones Analíticas

SUSANA SALVADOR A.
Jefe de Determinaciones Analíticas

NOTE: The results for the other elements requested with this batch/LAB will be reported once ICP analysis resumes.

INSTITUTO ECUATORIANO DE MINERÍA
DEPARTAMENTO DE LABORATORIOS
CHEMICAL ANALYSIS REPORT

LAB N°: 3671 DELIVERY: Ing. Iván Endara DATE: 87-06-08
N° of SAMPLES: Eight Jefe de Laboratorios
REQUESTED BY: Ing. F. Viteri RECEPTION: Ing. W. Santamaría DATE: 87-06-08
PROJECT: Cordillera Real Director de investigación geológica
ORIGIN: Azuay-Cañar; Sigsig-Chigüinda (see Litherland, 1987, Map 14)

DETERMINATIONS

SAMPLE CODE	Zn (ppm)	Pb (ppm)	Co (ppm)	Cu (ppm)	Ni (ppm)	Cr (ppm)
A-097	451	160	21	104	45	45
A-098	208	95	38	30	70	52
A-099	106	109	23	17	59	54
A-100	95	88	16	17	48	42
A-101	88	36	10	13	27	20
A-102	80	80	23	29	54	61
A-103	60	44	11	14	31	30
A-104	85	60	14	14	37	40

ASSAYED BY: Determinaciones Analíticas

SUSANA ALVARADO A.
Jefe de Determinaciones Analíticas

NOTE: The As results will be reported at a later date.

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INSTITUTO ECUATORIANO DE MINERÍA
DEPARTAMENTO DE LABORATORIOS
CHEMICAL ANALYSIS REPORT

LAB N°: 3595 DELIVERY: Ing. Iván Endara DATE: 87-07
N° of SAMPLES: Thirty-eight Jefe de Laboratorios
REQUESTED BY: Ing. F. Viteri RECEPTION: Ing. W. Santamaría DATE: 87-07
PROJECT: Cordillera Real Director de investigación geológica
ORIGIN: Various (Cañar – Azuay – Morona Santiago); Paute- Méndez (see Litherland, 1987, Map 12)

DETERMINATIONS

SAMPLE CODE	As (ppm)
A0039	104
A0040	96
A0041	46
A0042	40
A0043	70
A0044	58
A0045	78
A0046	112
A0047	56
A0048	48
A0049	84
A0050	70
A0051	68
A0052	100
A0053	52
A0054	82
A0055	52
A0056	56
A0057	74
A0058	104
A0059	82
A0060	40
A0061	58
A0062	60
A0063	98
A0064	70
A0065	52
A0066	62
A0067	64
A0068	82
A0069	92
A0070	74
A0071	100
A0072	52
A0073	76
A0074	56
A0075	64
A0076	70

ASSAYED BY: Determinaciones Analíticas

MARIANA LÓPEZ
Jefe de Determinaciones Analíticas

APPENDIX 3

NATURAL ENVIRONMENT RESEARCH COUNCIL
SCIENTIFIC SERVICES

ISOTOPE GEOLOGY CENTRE

RADIOGENIC ISOTOPES SECTION

Report No. 87/1

by

C. C. Rundle

Rb-Sr analysis of rocks collected in May/June 1987
for the ODA-funded Cordillera Real Project, Ecuador

Rb-Sr results from Ecuador – 1987

1. Foreword

Because of the difficulty of access, poor exposure, and high degree of weathering and alteration of many of the rocks in the Cordillera Real, it was often impossible to collect a full suite of samples which were all taken from outcrop and were undoubtedly from the same rock body. In several cases recourse had to be made to boulders in streams in order to make up numbers, or in an attempt to extend the likely range in Rb/Sr ratios. For the same reason at some localities samples of late cross-cutting aplite or felsite veins were collected, on the assumption that they were emplaced from the same magma only shortly after the main intrusion and thus would lie on the same isochron.

In some cases this approach seems to have been successful but in general the inclusion of loose boulders from streams has only complicated the interpretation and it is apparent that, although this type of sample may be useful to the field geologist in that it represents a sampling of inaccessible outcrops further upstream, it is of little use for precise isotopic dating - particularly by the Rb/Sr whole-rock isochron technique. These samples may indicate the presence of an igneous complex higher up the mountain, but it appears that only in a few favourable circumstances are the different members of the complex sufficiently coeval and consanguineous to be included in one Rb-Sr isochron suite.

Many of the rock suites analysed here have not yielded isochrons and a considerable amount of data selection has been necessary in order to produce apparently meaningful results. In many cases the only criterion for rejecting data points was that they did not appear to lie on the line defined by the majority and it is hoped that further petrographic details may help to justify these rejections. Overall, many of the regression results are unsatisfactory and it is clear that later alteration and modification have profoundly disturbed some of the Rb/Sr isotopic systems. Nevertheless, some of the sample suites apparently give undisturbed, original ages. It is hoped that further analysis of separated minerals by the K-Ar method, to be reported separately, will at least be able to define the age and extent of these later events. In order to obtain the ages of early events in the evolution of the area, particularly in the metamorphic basement, it may be more rewarding to utilise the U/Pb method on zircons; but it must be noted that this will only be of value for the relatively young rocks found in the Andean mobile belt if samples can be found in which the zircons are completely undisturbed by later events and record concordant ages by both U/Pb decay schemes.

Table 1 gives a summary of the various isochron regression analyses and this is followed by a detailed discussion of the results for each of the collected rock suites. The order of presentation and discussion of the data follows the logistics of the sample collection and has no particular geological significance. A table of full analytical results (Table 3) and various isochron regression diagrams are included at the end of the report.

2. Introducción

Details of samples collected from the Cordillera Real project area and crushed in Ecuador for Rb-Sr dating were documented in IGU Report No.87/12. This present report documents the analytical results and geochronological interpretation of the data for the benefit of the field geologists who commissioned the work and thus does not include a full description of the geology or any discussion of the wider geological implications of the results - these should be covered in a later, joint, publication. All rock descriptions given here are based on simple field and hand-specimen characteristics; subsequent discussions of geological and petrological details yet to be provided by the field geologists may lead to a reassessment of some of the conclusions and a clarification of some of the problems of interpretation.

One hundred samples representing thirteen different rock units, mainly granodioritic intrusives, were analysed for Rb/Sr ratios by X-ray fluorescence analysis using a Philips automatic XRF spectrometer in the laboratory of the British Geological Survey's Analytical Chemistry section under the supervision of Mr. T.K. Smith and colleagues; Mr. D. A. Bernard (NSS Isotope Geology Centre) is thanked for making the pressed powder pellets required for this purpose. Strontium isotope ratios were determined by the author using the clean-chemistry laboratory and multi-collector mass spectrometer in the Isotope Geology Centre. The results are presented in the form of tables and Rb-Sr isochron diagrams.

For samples with more than 30 ppm of either element a blanket error of $\pm 0.5\%$ (1 Sigma) was assigned to the Rb-Sr ratio determination. In other cases, a calculated error based on the counting statistics was used. Replicate analyses of samples and standards suggests that an error of $\pm 0.005\%$ is appropriate for the strontium isotope ratio measurements. Replicate analyses of international standards indicates that the results are accurate within the precision estimates.

The errors on age and initial ratio (Ri) are quoted as 2-sigma (95% confidence level) and refer to the last significant figure. Best-fit lines on the isochron diagrams were calculated using a least-squares fitting programme with errors assigned to both axes. Where the calculated parameter MSWD exceeds 3.0 it is inferred that the points do not all fit the line within the limits of analytical error and, following conventional practice, the errors on age and intercept have been enhanced by multiplying by the square root of the MSWD in order to make some allowance for the excess "geological" scatter. It must be noted, however, that when the MSWD is large this indicates that the system does not meet the requirements for a good geochronometer and the calculated age may have little geological significance.

All ages were calculated using a decay constant for ^{87}Rb of $1.42 \times 10^{-11} \text{a}^{-1}$.

Table 1. Summary of Rb-Sr Isochron regression results, Ecuador-1987

Intrusion	Sample No.	N	MSWD	Initial $^{87}\text{Sr}/^{86}\text{Sr}$	Age (Ma) & Error (2σ)
Chingual	E/87/2	10	8.2	0.7037 ± 2	146 ± 58
	Remove A, B, E, F, G	5	1.0	0.7029 ± 3	304 ± 55
	Remove A and H	8	2.8	0.7037 ± 1	$156 \pm 21^*$
Abitagua (North)	E/87/5	9	0.9	0.7046 ± 1	$161 \pm 2^*$
Abitagua (South)	E/87/6	11	24.9	0.7046 ± 2	166 ± 6
	Remove A, C, E, F	7	2.5	0.7046 ± 1	$163 \pm 2^*$
Abitagua (all)		20	14.8	0.7046 ± 1	165 ± 4
	Remove 6C, 6E, 6F	17	2.5	0.7046 ± 1	$162 \pm 1^*$
Azafrán + aplite and pegmatite veins	E/87/8	9	135	0.7064 ± 9	88 ± 16
Granite only		7	2.4	0.7046 ± 3	$120 \pm 5^*$
Mina Peggy	E/87/14	4	1028	0.702 ± 3	406 ± 112
Volcanic removed	14B	3	22.8	0.718 ± 1	$82 \pm 28^*$
Napurca (Zamora, NW)	E/87/16	8	57	0.7048 ± 3	187 ± 18
	Remove A, B, C	5	2.9	0.7046 ± 1	$187 \pm 2^*$
Felsite removed	16D	4	3.4	0.7047 ± 1	178 ± 23
Mafic	All except G and H	6	64	0.7049 ± 3	183 ± 19
Zamora (NE)	E/87/21	10	54	0.7056 ± 4	126 ± 41
	Remove C, H, I, J	6	4.2	0.7050 ± 3	$198 \pm 34^*$
Zamora batholith North-all		16	67	0.7047 ± 5	220 ± 64
Obvious outliers omitted		11	12.4	0.7047 ± 3	$236 \pm 31^*$
Río Pituca (Zamora S)	E/87/22	8	86.8	0.7046 ± 4	159 ± 17
	Remove G, H	6	4.4	0.7037 ± 2	246 ± 17
	Remove E, F	4	1.4	0.7038 ± 2	$244 \pm 19^*$
	only E, G, H	3	2.5	0.7040 ± 1	166 ± 2
Sabanilla migmatite	E/87/23	8	175	0.7118 ± 12	233 ± 51
Least foliated	Remove F	7	98	0.7118 ± 9	240 ± 40
Leucocratic	Remove B, E, G	4	20.6	0.7121 ± 5	$234 \pm 19^*$
Río Mayo pluton	E/87/26	5	2.7	0.7051 ± 2	$144 \pm 35^*$
Portachuela pluton	E/87/27	7	96	0.7049 ± 3	33 ± 11
San Lucas	E/87/28	9	543	0.7050 ± 8	62 ± 29
Granitic samples		3	1.6	0.7047 ± 1	$53 \pm 2^*$
Gneissic basement		4	0.9	0.7049 ± 1	$107 \pm 2^*$

*preferred results

Table. List of all figures - all isochron diagrams

Figure	Isochron diagram
1	Chingual gneiss– all samples
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3. Chingual gneiss (CCR/E/87/2A-J)

Ten samples of foliated granite/orthogneiss were collected from four localities along an 8km road section where small streams had produced gorges cutting across the road. All samples were very similar with streaky, flattened clots of variably fresh biotite in a matrix of sugary white feldspar and quartz; the only visible variation being the proportion and degree of alteration of biotite. On the isochron diagram (Fig. 1) all the samples do not define a line within the limits of analytical error (MSWD=8.2) and the age is 146 ± 58 Ma; $R_i=0.7037 \pm 2$. From visual examination of the isochron diagram, however, it is apparent that five of the samples (CCR/E/87/2C, D, H, I, J) are co-linear. Regression of these data produces an isochron (MSWD=1.0, Fig. 2) giving an age of 304 ± 55 Ma; $R_i=0.7029 \pm 3$; but it must be stressed that there is no obvious geological or geographical reason for selecting these five samples other than that they appear to define a separate line on the isochron diagram. The initial ratio for this line is unusually low for this part of the Andes and may indicate less crustal contamination in the genesis of this rock, or it may be spurious and due to later strontium loss during alteration. Further analysis by the Sm-Nd method could help to resolve this problem (if the project leader considers this to be worthwhile).

The remaining five samples scatter to the left and above this line. This could be explained by loss of Rb during a later metamorphism (though it is not clear why only these five should have been affected) and it is interesting to note that all of them have significantly lower Rb contents than those which define the line. If the five co-linear samples have indeed remained closed systems since initial emplacement, then these data would suggest that this took place in the late Palaeozoic and involved mainly pristine mantle-derived material.

Further examination of the hand specimens, however, suggests an alternative interpretation. Sample 2H is rather different from the rest in that it contains the highest proportion and finest grained biotite. Moreover, analysis of the isochron data demonstrates that this sample lies furthest from the best-fit line through all ten data points. If this point is omitted from the regression, the MSWD reduces to 4.7 and the age becomes 149 ± 44 Ma. Further omission of sample 2A, which again is slightly anomalous in that it contains a peppering of fine-grained biotite in the ground mass, yields an isochron (MSWD=2.8, Fig. 3) with an age of 156 ± 21 Ma; $R_i=0.7037 \pm 1$. In the light of the other results in this study, it is considered that this is probably the best interpretation of these data.

4. Abitagua granite (North) (CCR/E/87/5A-I)

Nine samples were collected from a road cutting along a 3-km section of continuous exposure. All samples are rather altered and contain biotites with oxidised rims. The rock is an unfoliated, medium grained-to-porphyritic biotite granodiorite. Sample 5H contains fine, late, felsite veins and 5I is pure fine-grained felsitic material. Despite the altered appearance of these samples and the inclusion of obviously later vein material, all nine samples define an isochron (Fig. 4, MSWD=0.9) giving an age of 161 ± 2 Ma; $R_i=0.70456 \pm 4$. It must therefore be assumed that alteration and vein emplacement took place shortly after intrusion and thereafter the system remained closed to isotope migration.

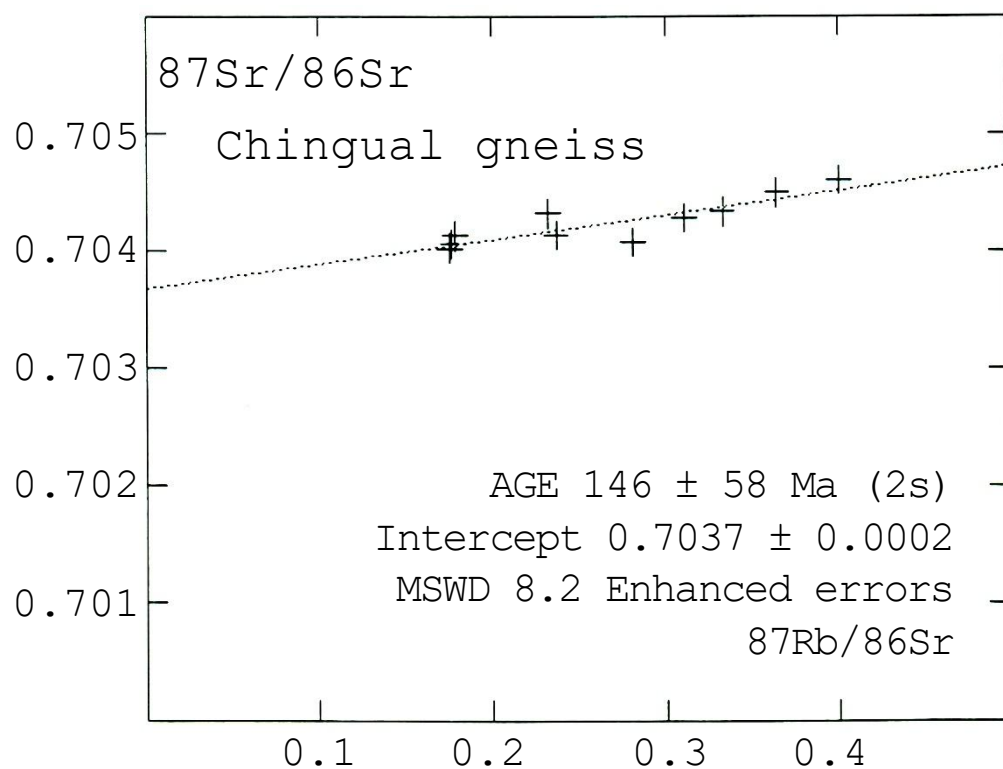


Figure 1. Chingual gneiss – all samples

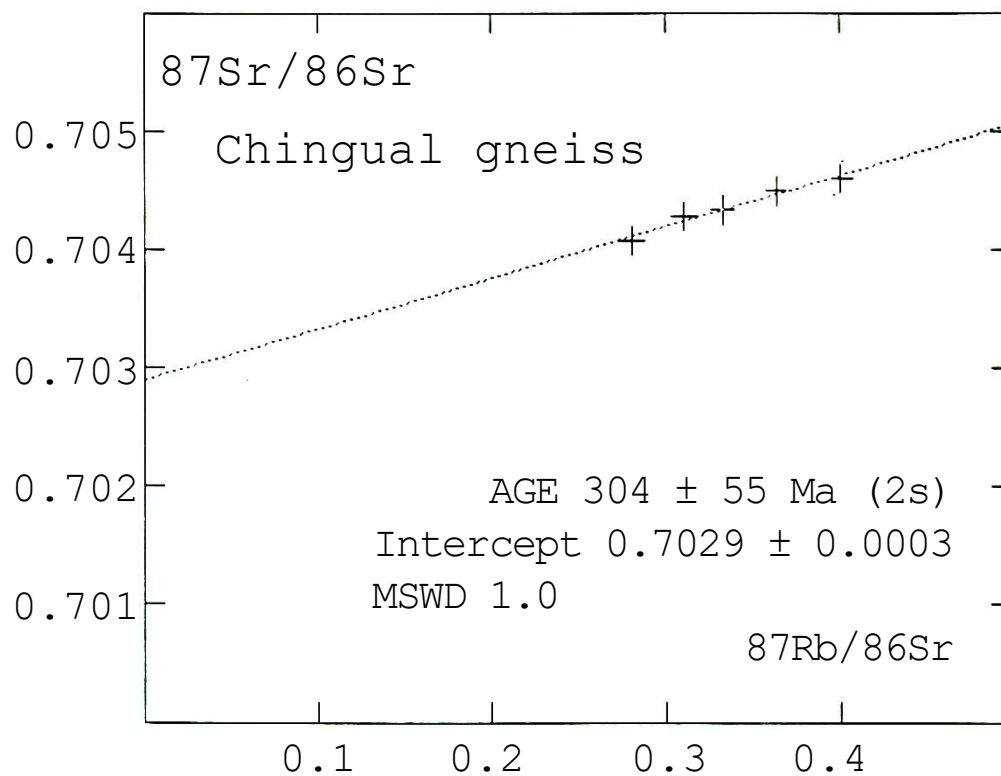


Figure 2. Chingual gneiss – five selected samples

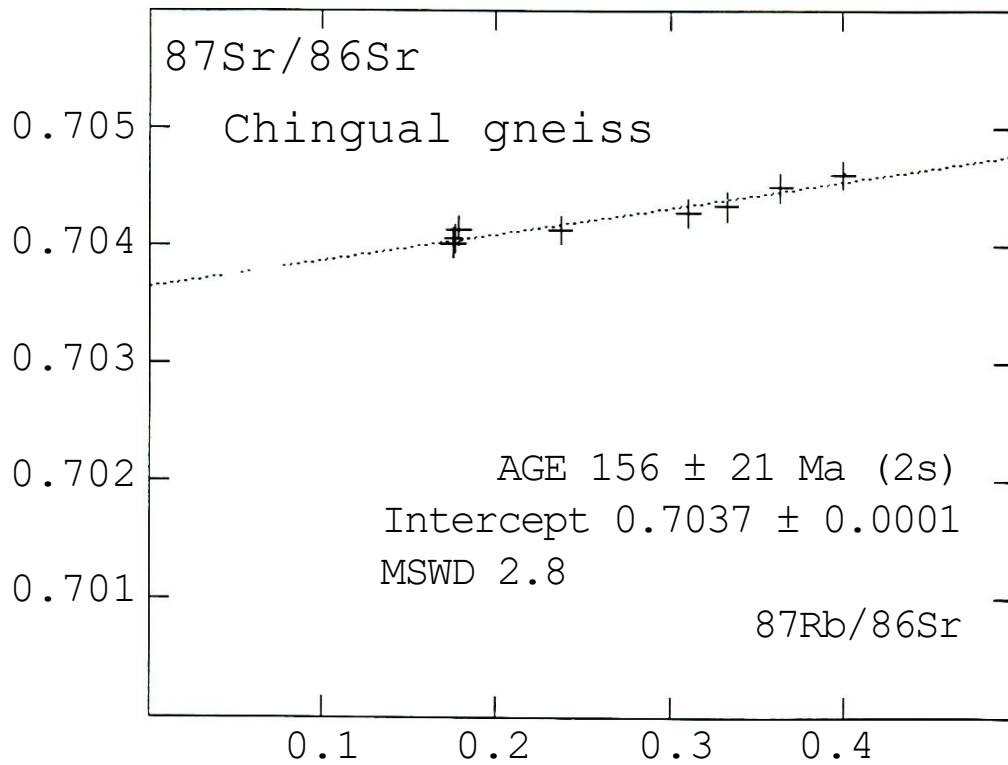


Figure 3. Chingual gneiss – minus two outliers

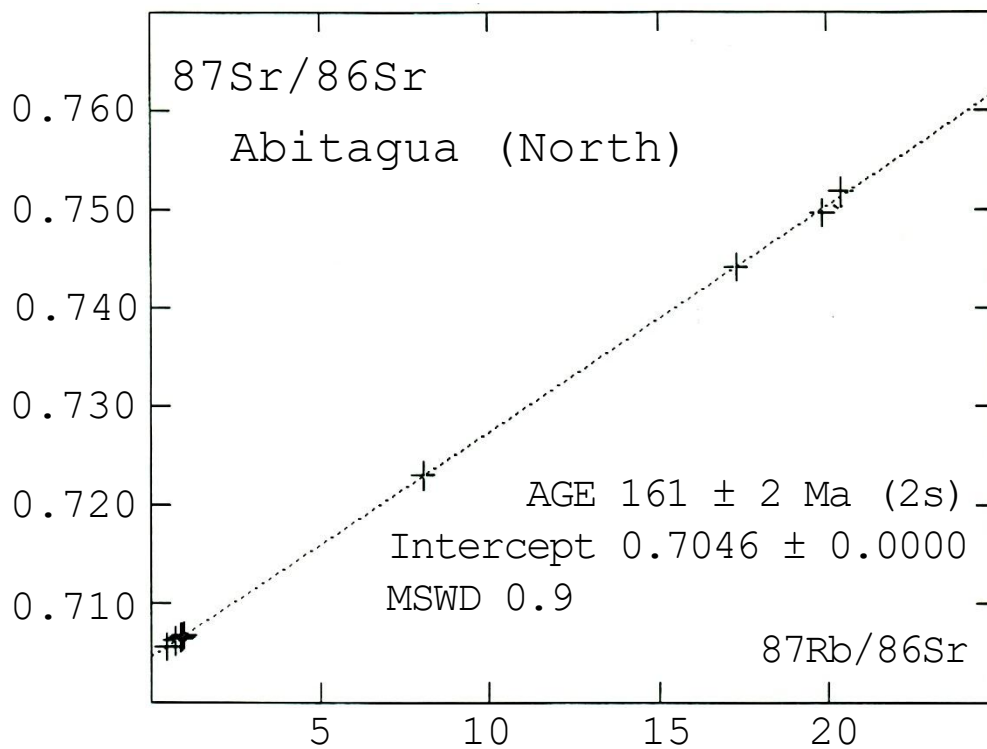


Figure 4. Abitagua granite (North)

5. Granito Abitagua (Sur) (CCR/E/87/6A-K)

Eleven samples, mostly rather less altered than the northern suite, do not all define a line on the isochron diagram (Fig. 5, MSWD=25) nevertheless the age and intercept (166 ± 6 Ma, $Ri=0.7046 \pm 2$) are very similar to those for the northern outcrop. Moreover, if the four most obvious outliers are omitted (6C, 6E and 6F with coarse pink feldspars, and 6A which is very altered with abundant fine-grained oxidised biotites), the remaining seven (including a late felsite vein) define an isochron (MSWD=2.5, Fig. 6) giving an age of 163 ± 2 Ma; $Ri=0.70458 \pm 5$; almost identical to that given by the Northern outcrop.

If the two sets of data are combined the result is a seventeen-point isochron (MSWD=2.5, Fig. 7) with an age of 162 ± 1 Ma, $Ri=0.70459 \pm 3$. With so many samples defining this line there can be a high degree of confidence that it records a significant geological event; presumably final cooling after emplacement and subsequent alteration.

6. Azafrán granodiorite (CCR/E/87/8A-I)

The nine samples of variably foliated and epidotised medium-grained biotite granodiorite included one fine-grained aplite vein and a later quartz-feldspar pegmatite. These two later samples lie well off the line defined by the seven normal samples and when these are omitted the isochron age is 120 ± 5 Ma; $Ri=0.7046 \pm 3$; MSWD=2.4 (Fig. 8). The initial ratio is the same as that for Abitagua but the age is significantly younger. This provides strong evidence that the Azafrán intrusion is younger than Abitagua and suggests that the foliation seen in the former is a marginal flow effect rather than a tectonic overprint.

7. Río Verde complex (CCR/E/87/10A, B)

Two samples from a small outcrop of Hb+Bt diorite containing sporadic crystals of blue quartz were collected from a small outcrop on the west bank of the Río Verde in order to investigate if this rock is related to either of the nearby Abitagua or Azafrán intrusions. Both the samples were very similar in hand specimen and have very similar (and low) Rb/Sr ratios. Hence no meaningful age can be calculated for these two alone; and a model age calculation using an assumed initial ratio is not appropriate because the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio is so low that the calculated age would be too dependent on the particular value chosen for the initial ratio. If these two samples are plotted on the isochrons for Azafrán and for Abitagua (South) the same effect is observed. In both cases the two points plot at the lower end and slightly above the isochron and lead to an increase in the MSWD. Thus, it would appear from these data that the Río Verde samples are not related to either the Abitagua or the Azafrán intrusions and may actually be slightly older than either of them. Further isotopic analysis of separated minerals may help to resolve this problem, but it is also suggested that a geochemical and petrographic study of these intrusions would aid in the correlation.

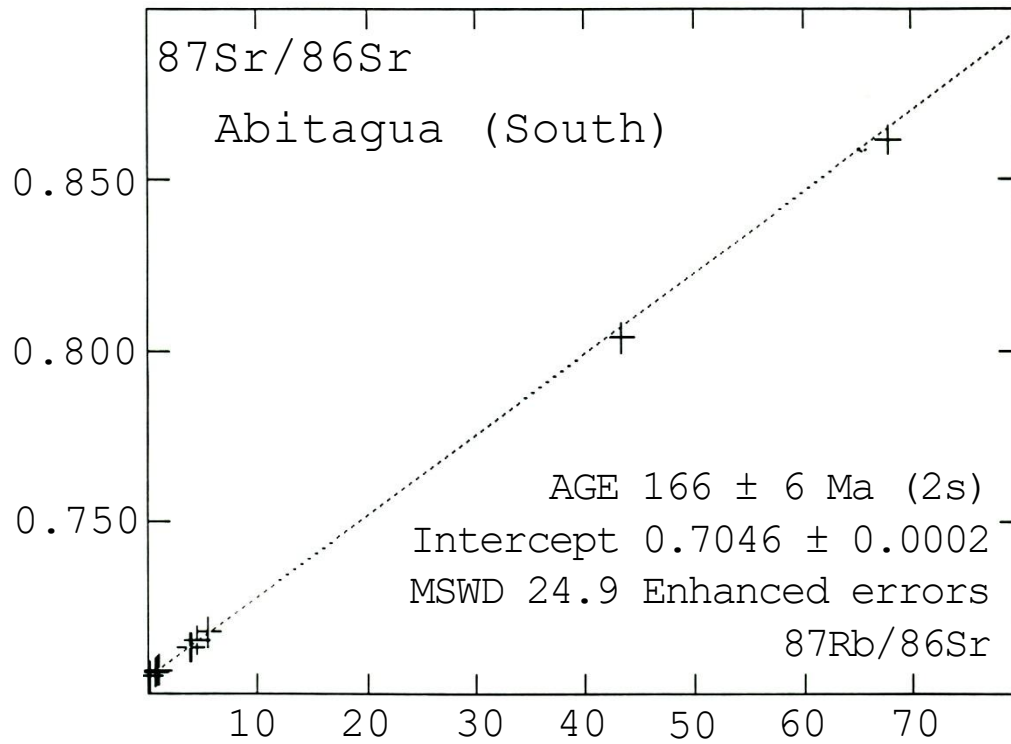


Figure 5. Abitagua granite (South) – all samples

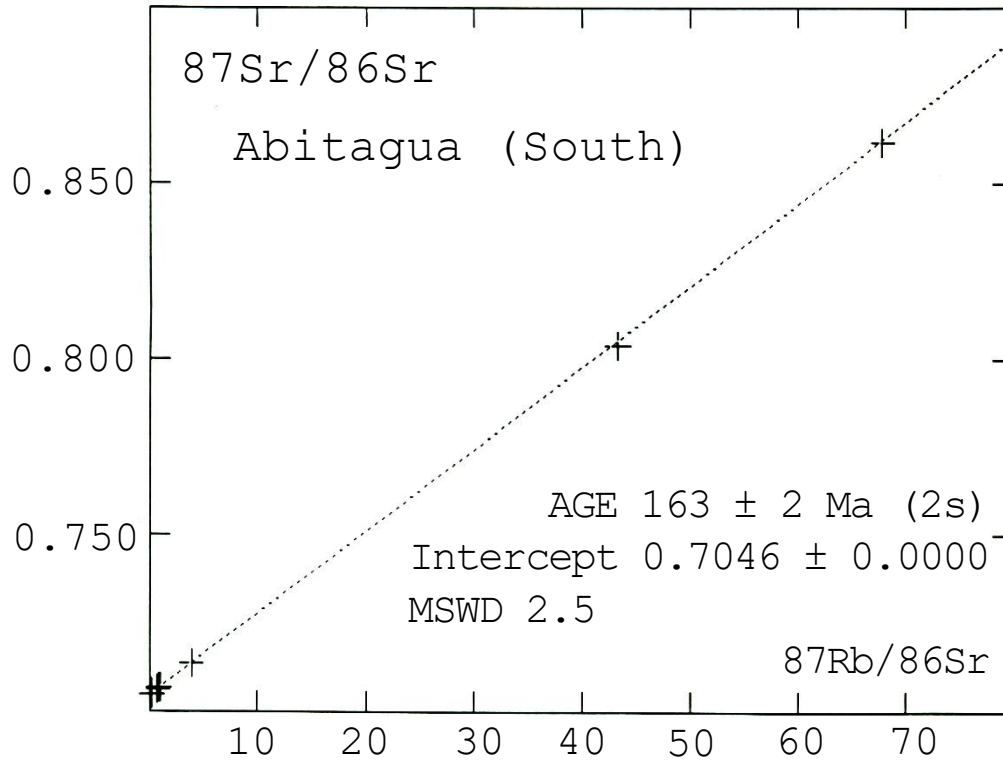


Figure 6. Abitagua granite (South) – minus four outliers

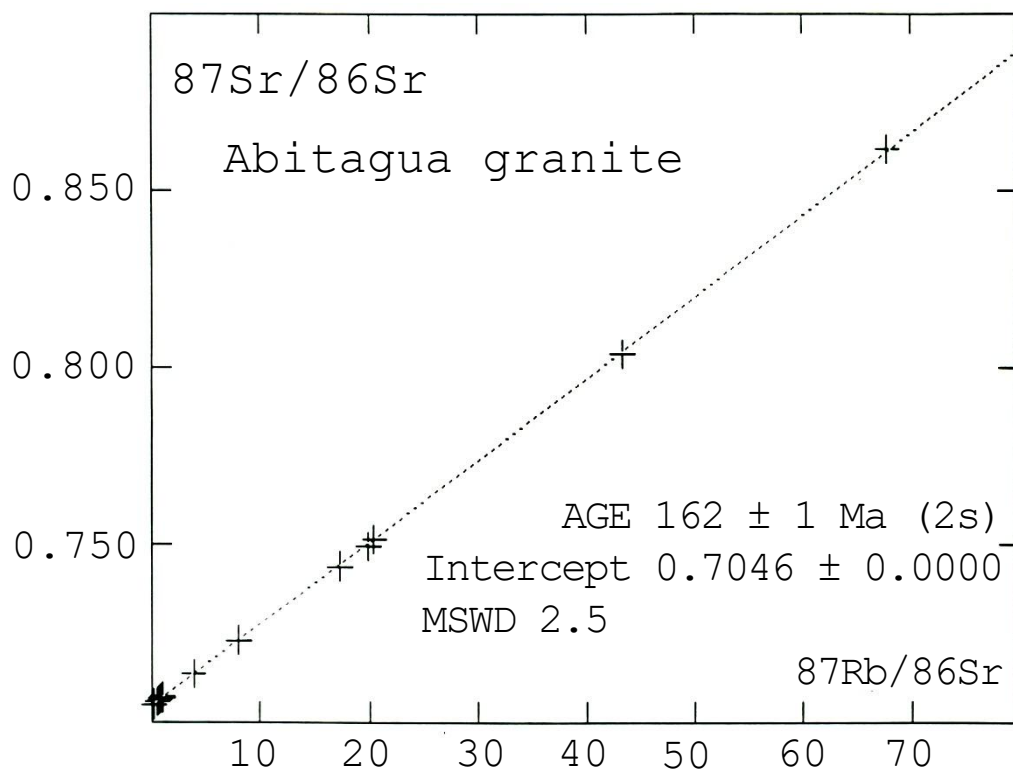


Figure 7. Abitagua granite – combined data

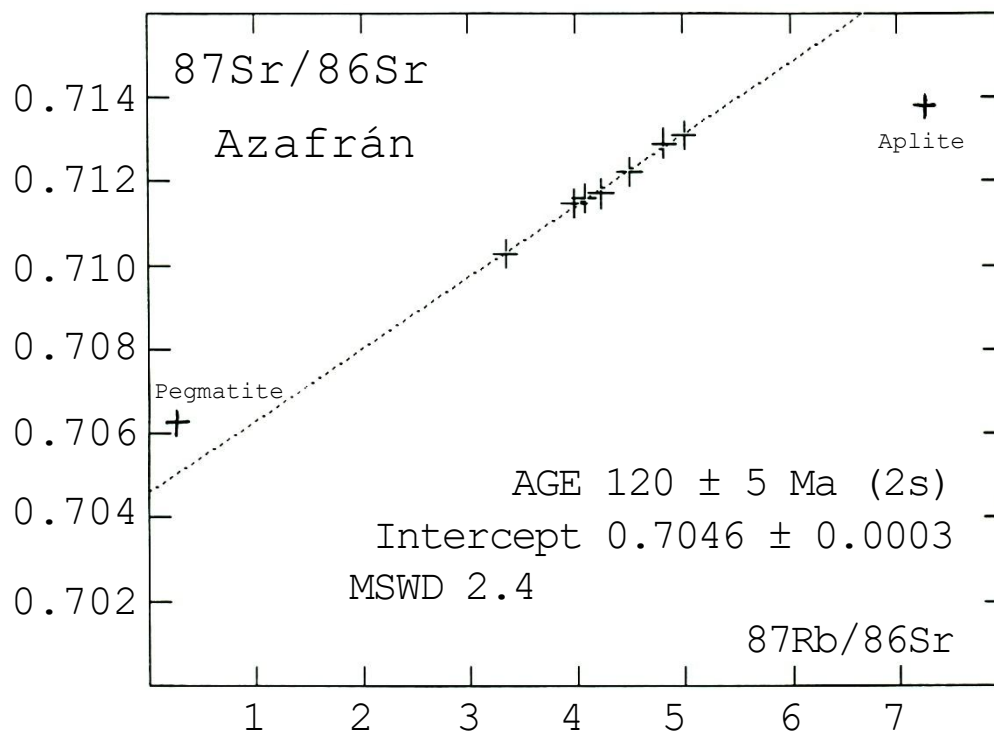


Figure 8. Azafrán granodiorite

8. Peggy Mine blue quartz granite (CCR/E/87/14A-D)

Because of difficult access and lack of exposure, only four samples of this rock were collected - all from large boulders in a stream bed. Three were of medium-to-coarse grained grey biotite granite with occasional small blue quartz crystals and large grey K-feldspar megacrysts, whilst one (14B) was a fine-grained volcanic facies which it was hoped was related to the granite and would help to extend the range of Rb/Sr ratios.

Examination of Fig. 9, however, demonstrates that this was not the case. The data for the volcanic sample lies well away from those for the other three samples and does not appear to be related. Unfortunately, the remaining three granite samples still do not define an isochron (MSWD=22.8) and have only a small range in Rb/Sr ratios, thus little reliance can be placed on the results (82 ± 28 Ma, $R_i = 0.7176 \pm 14$). Nevertheless, these data indicate a high initial ratio and young age for these samples and strongly suggest that the isotopic systems are reflecting a late resetting episode - possibly related to the secondary crystallization of the feldspar megacrysts. It is hoped that further analysis of separated biotite may help to throw some light on the age of emplacement, but it is suggested that U/Pb analysis of zircon may be the best method by which to attempt to date this rock.

9. Zamora batholith

9.1 Napurca pluton (Zamora North-West) (CCR/E/87/16A-H)

Eight samples collected along a 5 km road section included five very similar medium-to coarse-grained hornblende granodiorite samples, one felsite vein, and two very different fine-to medium-grained pyritised mafic samples. The coarse samples are all rather altered; the mafic minerals are green, the feldspars are reddened, and there is abundant epidote veining. Moreover, the mafic samples lie on the opposite side of a small fault to the granitic ones and were taken from rounded boulders in a stream bed.

If all the samples are regressed together (Fig. 10) there is a considerable scatter (MSWD=57) and this can be seen to be due to the three granitic samples (A, B, C) collected at the northern end of the traverse. If these are omitted the remaining data define an isochron (MSWD=2.9, Fig. 11) giving an age of 187 ± 2 Ma; $R_i = 0.70461 \pm 4$. It must be noted, however, that the three omitted samples are identical, in hand specimen, to the two coarse granitic samples which do lie on the isochron. Moreover, this age is very dependent on the data for the late felsite vein sample (D) which has an $^{87}\text{Rb}/^{86}\text{Sr}$ ratio five times greater than any of the others. If this is omitted from the regression the MSWD rises slightly (to 3.4), the errors on the age and intercept increase dramatically because of the reduction in the range of Rb/Sr ratios, but the values for the age and intercept are not changed significantly at 178 ± 23 Ma; $R_i = 0.7047 \pm 1$. It is concluded that 187 ± 2 Ma is a good estimate of the age recorded in the felsite vein and that this is very similar to that recorded in the host rock.

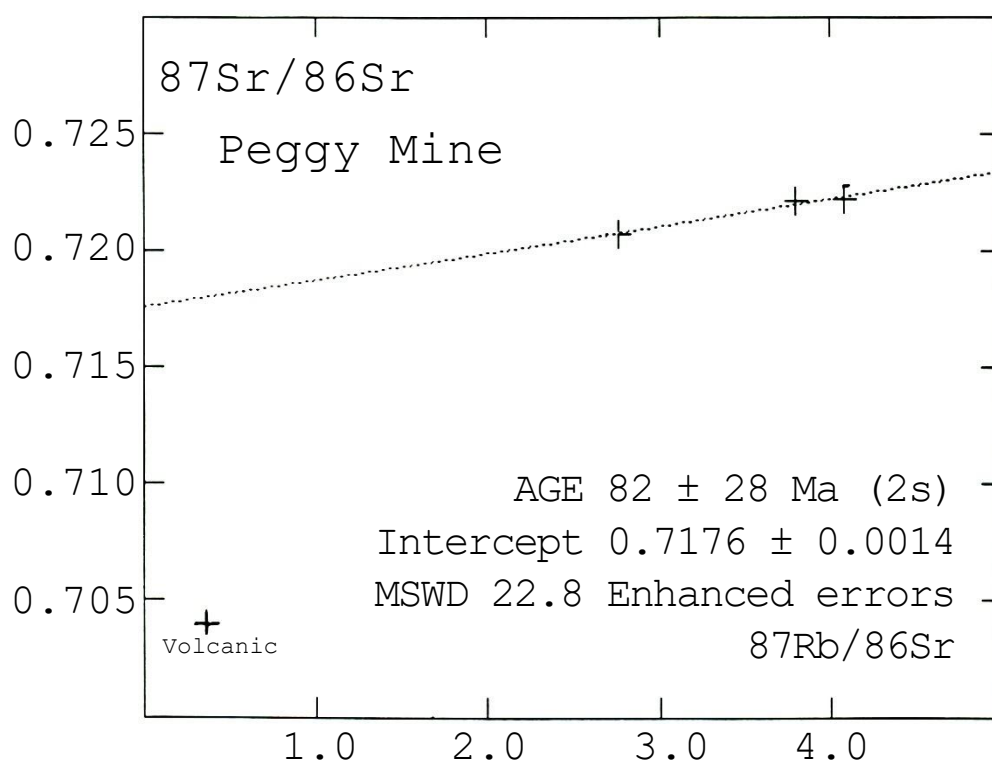


Figure 9. Peggy Mine granite

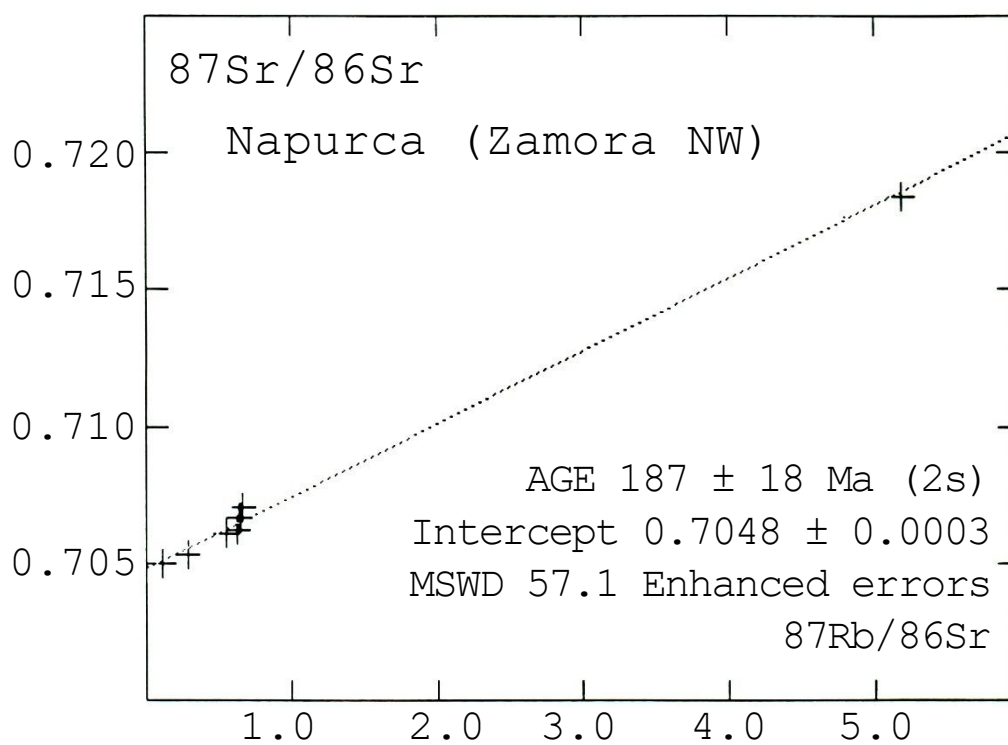


Figure 10. Napurca pluton – Zamora (North-West) – all samples

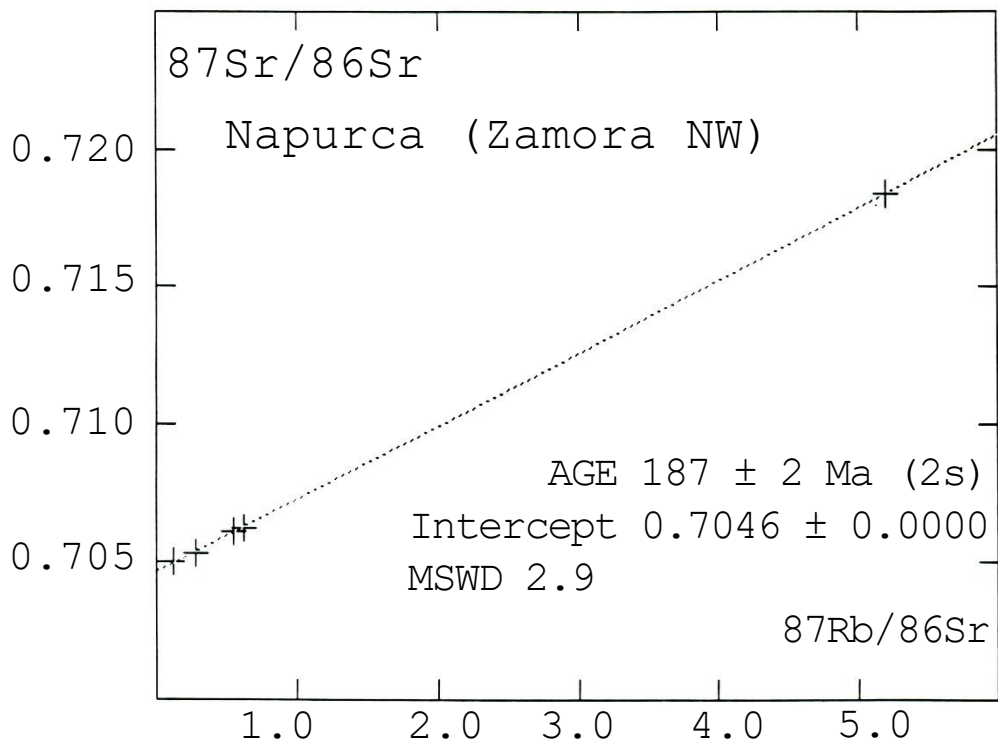


Figure 11. Napurca pluton – Zamora (North-West) – minus three outliers

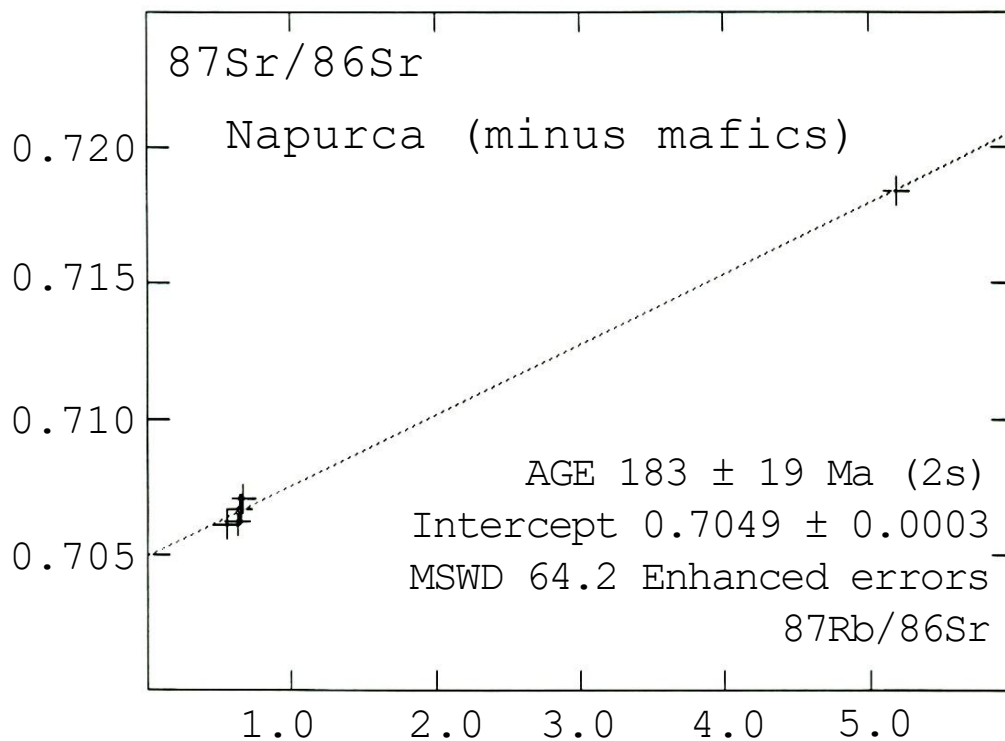


Figure 12. Napurca pluton – Zamora (North-West) – minus mafics

However, it must be noted that the five samples defining this age are very different in character and were collected from two exposures separated by a fault. Moreover, the two mafic samples were not in-situ. Geologically the most sensible grouping of data would be to plot the five granitic samples plus the felsite together; all of which were collected from the same side of the fault and from in-situ outcrop. In this case the MSWD is even higher than that for all the data and the age is again dependent on the felsite vein sample (Fig. 12, MSWD=64.2, 183 ± 19 Ma), but this time omission of the felsite results in a scatter of points (with MSWD=29.4), giving a virtually meaningless older age and lower initial ratio, with very high errors (569 ± 399 Ma; $R_i=0.7015 \pm 35$). Nevertheless, these data apparently provide confirmation of an age of around 185 Ma for the felsite vein and possibly for the pluton as a whole. Again, it is hoped that further analysis of separated minerals may help to substantiate this conclusion. Although not in-situ it would appear that the two mafic samples are related to the main granodiorite.

9.2 Zamora (North-East) (CCR/E/87/21A-J)

Seven samples were collected from residual boulders in deeply weathered granite gravel along a 1 km section of a partially completed new road cutting, whilst three were collected from boulders in a stream some 2 km away from the main outcrop. Samples A, B, E, F and G were all rather similar medium grained Hb+Bt granodiorite with occasional small pink feldspars. Mafics are generally rather green and small mafic xenoliths occur sporadically. Sample C was from a fine grained dark grey/green vein whilst D was a partially assimilated xenolith with secondary growth of quartz and feldspar. The three river boulders included H: similar to A, B etc. but more altered, I: a relatively fresh porphyritic volcanic facies, and J: a fine-grained homogeneous felsic block.

All ten samples show a wide scatter on the isochron diagram (Fig. 13, MSWD=52, age= 126 ± 41 Ma) and the two most obvious outliers (H and J) are two of the boulders from the river including the fine-grained felsitic variety with a high Rb/Sr ratio (both of which tend to reduce the slope, and hence the calculated age, of the best-fit line). If the three river samples are omitted the remaining seven outcrop samples still do not define an isochron though there is a considerable reduction in the scatter (MSWD=7.0) and the slope of the line is increased. Further elimination of sample 21C (the late fine-grained vein) reduces the MSWD to 4.2 (Fig. 14) and the age is 198 ± 34 Ma; $R_i=0.7050 \pm 3$.

Because of the high errors (mainly due to the low values and narrow range of the Rb/Sr ratios) these results are not significantly different from those for the Napurca pluton; but there is an indication of excess scatter and a suggestion of an older age which may suggest isotopic disturbance and partial resetting of older material. It may be significant that a line drawn through H and J alone gives an age of about 175 Ma, very similar to that determined for the felsite vein in the Napurca pluton.

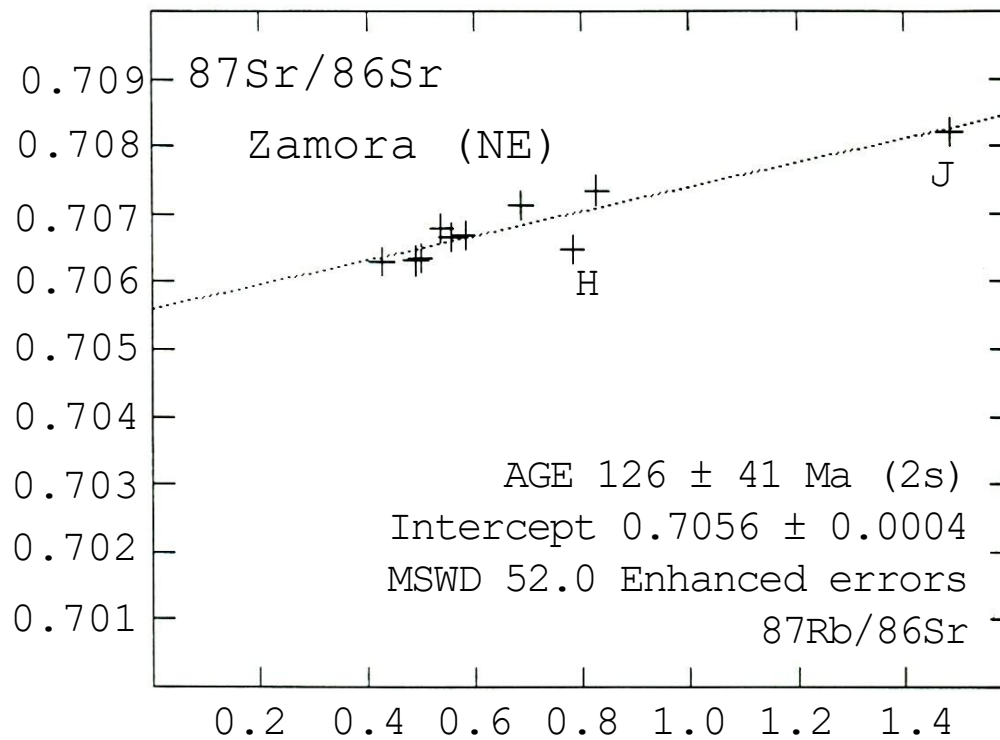


Figure 13. Zamora (North-East) – all samples

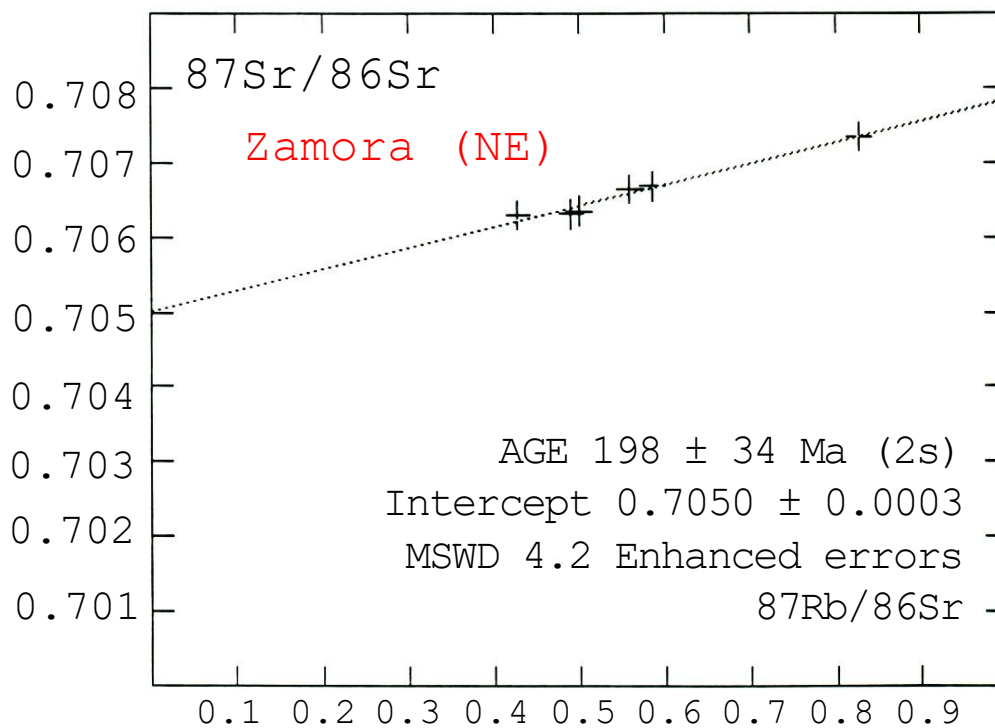


Figure 14. Zamora (North-East) – coarse outcrop samples only

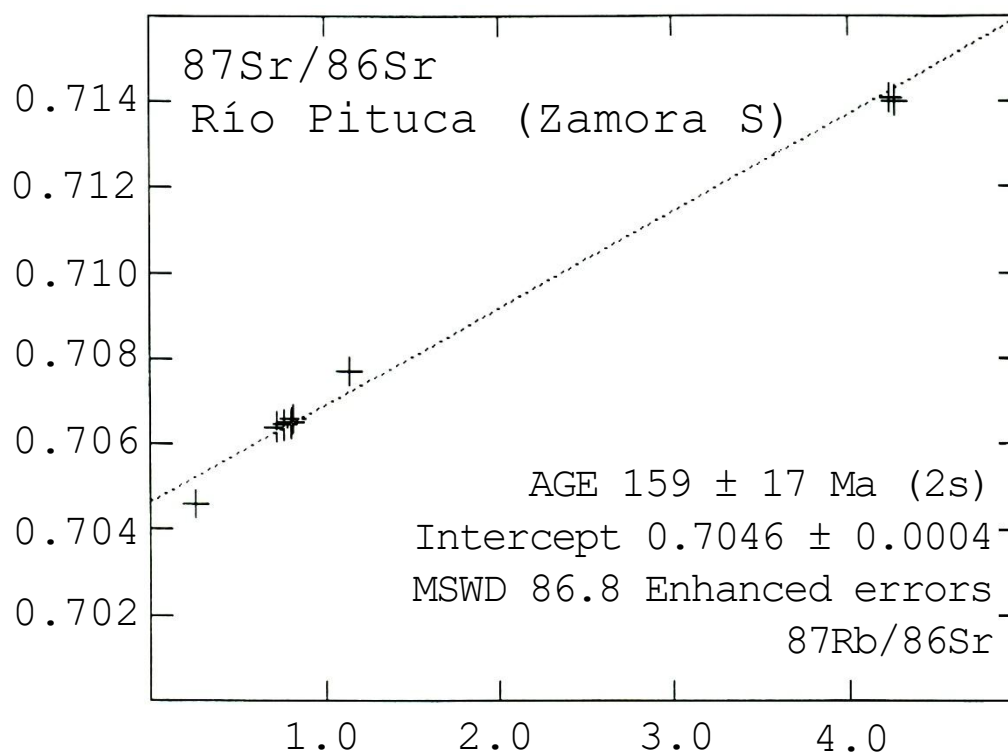


Figure 15. Río Pituca (Zamora south) – all samples

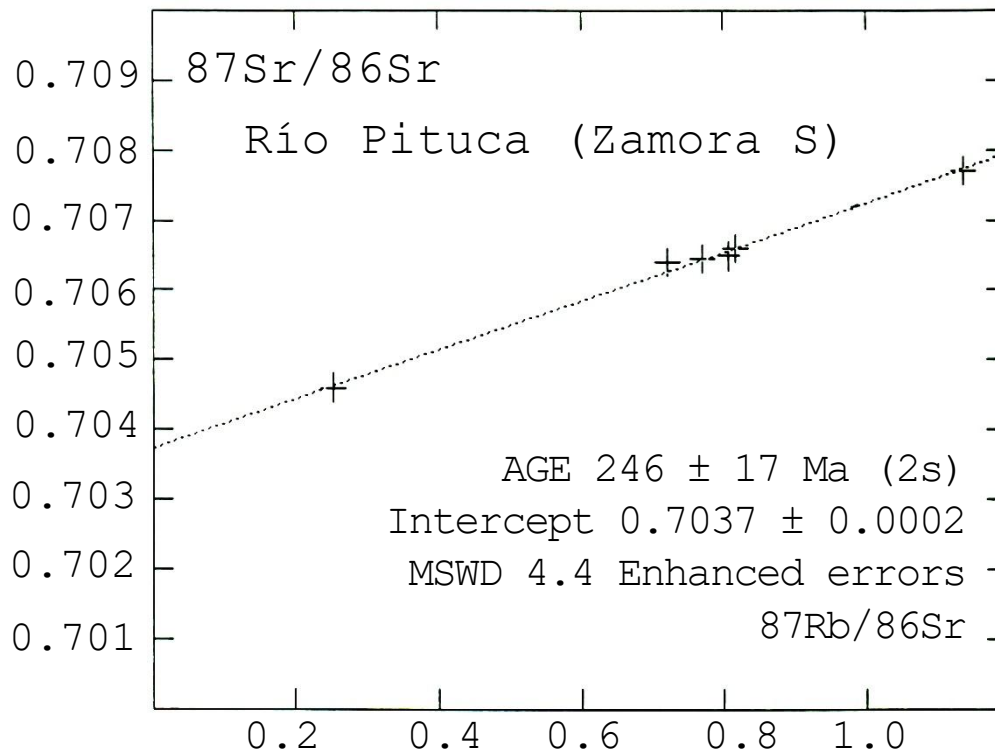


Figure 16. Río Pituca (Zamora south) – minus veined samples

9.3 Río Pituca (Zamora South) (CCR/E/87/22A-H)

Four samples taken from large boulders in a field yielded fresh samples of coarse-to medium-grained Hb+Bt granite with pink K-feldspar phenocrysts. Four more samples taken from large boulders in a river bed some 500 meters away were more variable. E was similar to the first four but F was quite different. This was a very fresh leucocratic grey and white Hb porphyritic variety with no trace of pink feldspar. G and H were from a large boulder of originally coarse pink-feldspar granite which contained numerous large anastomosing patches of chloritic and epidotic veining/alteration and many basic xenoliths. On the isochron diagram (Fig. 15) the samples do not all lie on a line but the most anomalous points are G and H - the xenolithic veined variety, which have much the highest Rb/Sr ratios. If these are omitted, the remaining six (including the non-pink variety) lie on a reasonable line (MSWD=4.4, Fig. 16) giving an age of 246 ± 17 Ma; $R_i=0.7037 \pm 2$. The data from the four field samples alone give an isochron (MSWD=1.4) with an age of 244 ± 19 Ma; $R_i=0.7038 \pm 2$.

These data suggest an age in excess of 225Ma for this part of the Zamora batholith which is thus significantly older than those apparently recorded in the two northerly exposures. It is interesting to note here that the two veined samples plus the pink-feldspar granite sample from the river together give an isochron (MSWD=2.5) giving an age of 166 ± 2 Ma, $R_i=0.7040 \pm 1$. This is very similar to the age given by the Napurca pluton in the north and perhaps suggests that the late veining was related to this later event.

9.4 Summary of Zamora Batholith results

All suites of samples collected from this area give scattered results on the isochron diagrams and are difficult to interpret. The results from the two northern traverses are dominated by the two high Rb/Sr late felsite vein samples which tend to reduce the calculated ages. If these are omitted and all the northern samples are plotted together there is a wide scatter (Fig. 17) and the age is 220 ± 64 Ma; $R_i=0.7047 \pm 5$. Progressive removal of obvious outliers does not significantly alter these results but reduces the MSWD and thus reduces the errors. Ultimately an eleven-point line is produced in which no one sample appears particularly anomalous. The MSWD is 12.4 with an age of 236 ± 31 Ma; $R_i=0.7047 \pm 3$. This age is significantly older than the best ages calculated when the felsite veins are included and is very similar to that given by the southern exposure. The initial ratio of the northern suites is however significantly higher than that for the southern so that if both suites are plotted together, they lie on two parallel lines.

Thus, it is concluded that the best interpretation of these data is that the Zamora Batholith was originally emplaced in late Permian to early Triassic times. During intrusion the magma in the north seems to have assimilated more pre-existing crustal material than that in the south. Subsequently, in early Jurassic times, the isotopic systems suffered considerable modification and disturbance in a period of alteration, possibly accompanied by vein emplacement.

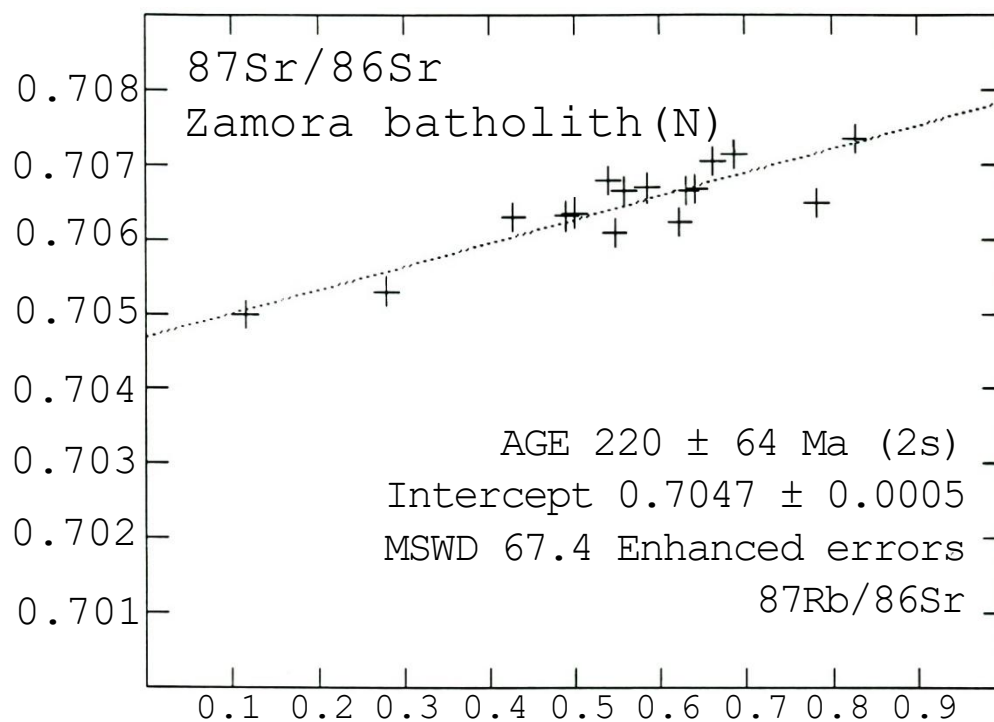


Figure 17. Zamora batholith – Northern samples only

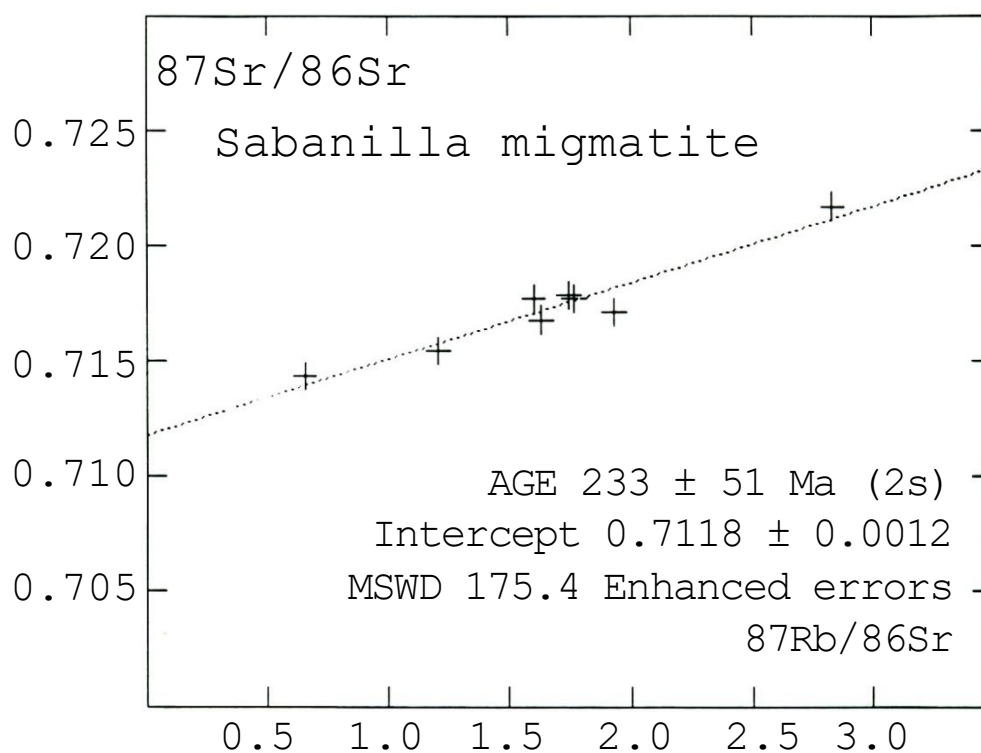


Figure 18. Sabanilla migmatite– all samples

10. Sabanilla migmatite (CCR/E/87/23A-H)

This rock was originally mapped by Kennerley who described it as a metasomatic granite intrusive. In the present investigation eight samples of highly variable migmatitic gneisses were collected along a 2 km section of continuous fresh exposure along a new road cutting. The rocks are strongly foliated and have obviously had a complex history. In one section angular blocks of foliated fine-grained material are scattered in random orientation in a matrix of highly foliated, chevron-folded gneisses which are themselves cut by quartz-feldspathic pods. Most exposures are of typical light and dark banded gneisses with variable intensity of folding, but more rarely a more massive, unfoliated, medium-grained granite, with minor quartz + feldspar + muscovite sweat-outs is seen; presumably this is the type described by Kennerley. All the samples contain abundant fresh secondary biotite.

On the assumption that the biotite-forming episode was the last event to affect these rocks and that at that time the strontium isotopes would have been homogenised it was decided to collect samples from all the various phases in an attempt to obtain a good spread in Rb/Sr ratios. On the isochron diagram (Fig. 18) the points scatter widely about the best-fit line (MSWD=175) and give an age of 233 ± 51 Ma with the unusually high initial ratio of 0.7118 ± 12 . This is strongly suggestive of disturbance and partial resetting of pre-existing crustal material. Removal of the most obvious outliers, including the least foliated more massive sample F and three samples of leucocratic mainly quartz-feldspar sweat-out material B, E, G leaves the four most mafic finely banded samples, which appear reasonably co-linear. Nevertheless, the MSWD, although somewhat reduced, is still high (20.6) and the age and intercept remain essentially unchanged at 234 ± 19 Ma; $R_i = 0.7121 \pm 5$ (Fig. 19).

It is clear from these results that the Rb/Sr isotope systems were not completely reset during the last metamorphic event, as was hoped, and thus do not now meet the requirements for a good geochronometer. The calculated age and intercept have high errors and may be reflecting two or more events and are not considered to be very reliable; they may be recording intermediate values, between end members. Nevertheless, it may be significant that these samples appear to be recording an age similar to that deduced for the emplacement of the nearby Zamora batholith - but it is impossible to say from these data whether this reflects initial emplacement of an intrusive body, gneissification, or later recrystallisation.

The high initial ratio would suggest that the genesis included a long-lived crustal precursor - possibly involving the melting of early sediments. K-Ar dating of separated micas should indicate the age of the last event affecting the area and if this is significantly younger than 230 Ma then this may indicate that the Rb/Sr age is more related to the gneissification, but it is suggested that petrological, geochemical, Sm-Nd, and U/Pb data may be required in order to throw further light on the early evolution of these rocks.

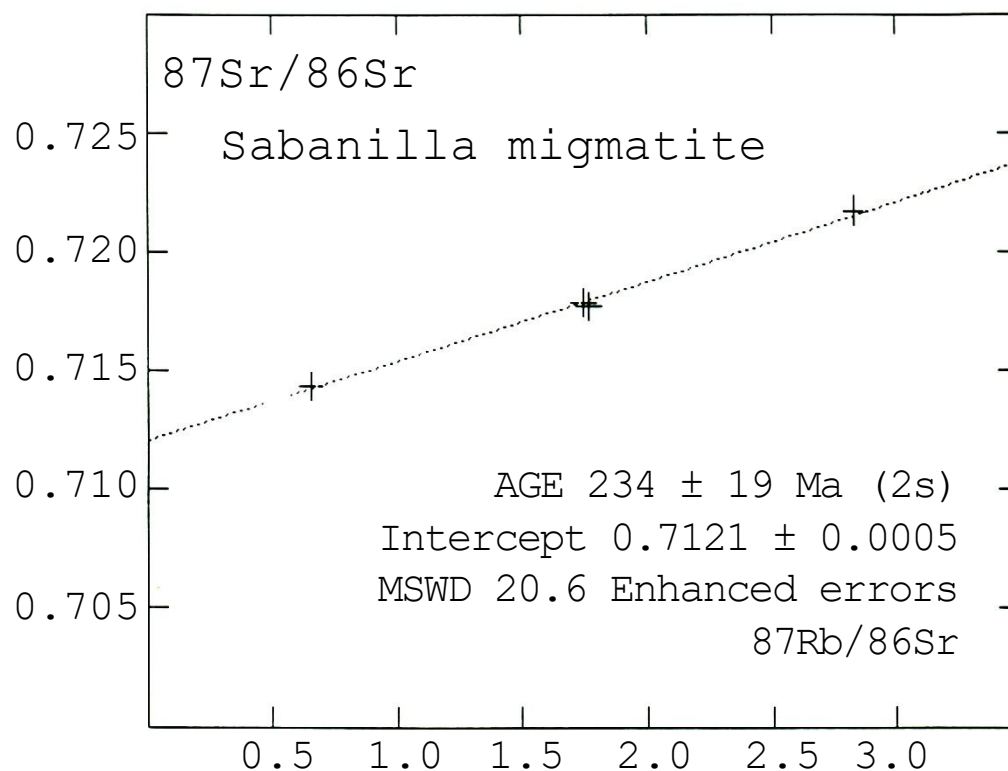


Figure 19. Sabanilla migmatite – mafic samples only

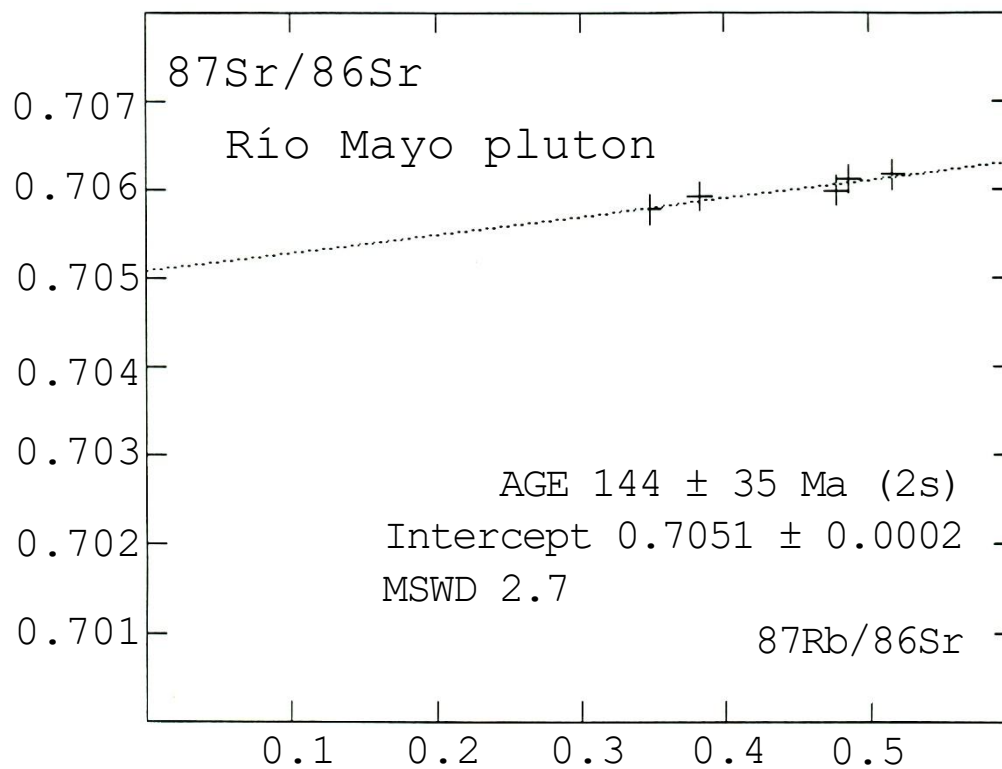


Figure 20. Río Mayo pluton

11. Río Mayo pluton (CCR/E/87/26A-E)

Although exposed continuously along the road-side for several kilometres this rock was so badly weathered and altered and had such a complex structure that it was only possible to collect five reasonably fresh samples of what appeared to be the earliest phase. This was a medium grained Hb+Bt granodiorite-to-diorite, cut by late porphyry dykes which are themselves cut by mafic dykes. In places large rafts of a medium-grained grey biotite-rich phase has a sharp contact with an equally medium-grained leucocratic phase. None of these later phases were sampled. It is thought by the field geologists that this pluton may be related to the nearby Zamora batholith.

When regressed together the data for all the five samples define an isochron (Fig. 20, MSWD=2.7) giving an age of 144 ± 35 Ma, $R_i=0.7051 \pm 2$. Despite the high error (due to the low spread in Rb/Sr) the age is significantly younger than the emplacement age inferred for the Zamora samples (though not from the age of the felsite veins and alteration in Zamora) and the initial ratio is significantly higher. Thus, these data suggest that either the Río Mayo pluton is younger and unrelated to Zamora or it experienced a more profound resetting during a Jurassic event. Because the errors are so high, it is impossible to say if this was the same event that affected Zamora. Again, it is suggested that further petrographic, geochemical and Sm-Nd isotope work may help to deduce the relationship between these rocks.

12. Portachuela pluton (CCR/E/87/27A-G)

This again consisted of a series of very poor exposures of highly variable rock type and was collected mainly for K-Ar dating of mafic minerals. Nevertheless, in view of the remoteness of the outcrop, it was also decided to attempt to date these samples by Rb-Sr. Figure 21 demonstrates that this was not very successful. Sample F is particularly anomalous with a much higher Rb/Sr ratio than the others, and dominates the line so that the calculated age of 33 ± 11 Ma is essentially a model age for this sample; which is a coarse pink-feldspar granite which appears to be the most altered in the suite. Nevertheless, the initial ratio of 0.7049 ± 3 is within the normal range found for most of the Ecuadorian rocks and suggests that the age may be a reasonable approximation to the original age of intrusion. Thus, it would appear from the data that the Portachuela pluton is probably part of the younger Cenozoic suite rather than Mesozoic.

The remaining samples form a cluster at the lower end of the line but are themselves widely scattered and no meaningful age can be calculated for them. It is hoped that K-Ar dating of separated minerals will confirm the age suggested by the Rb-Sr work.

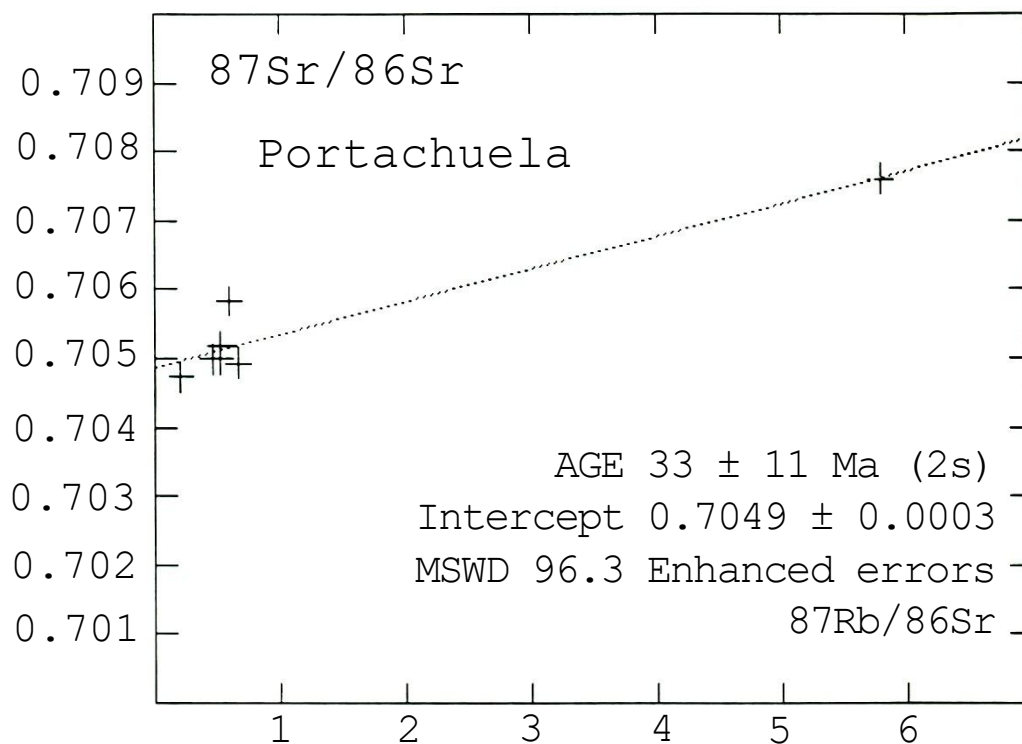


Figure 21. Portachuela pluton

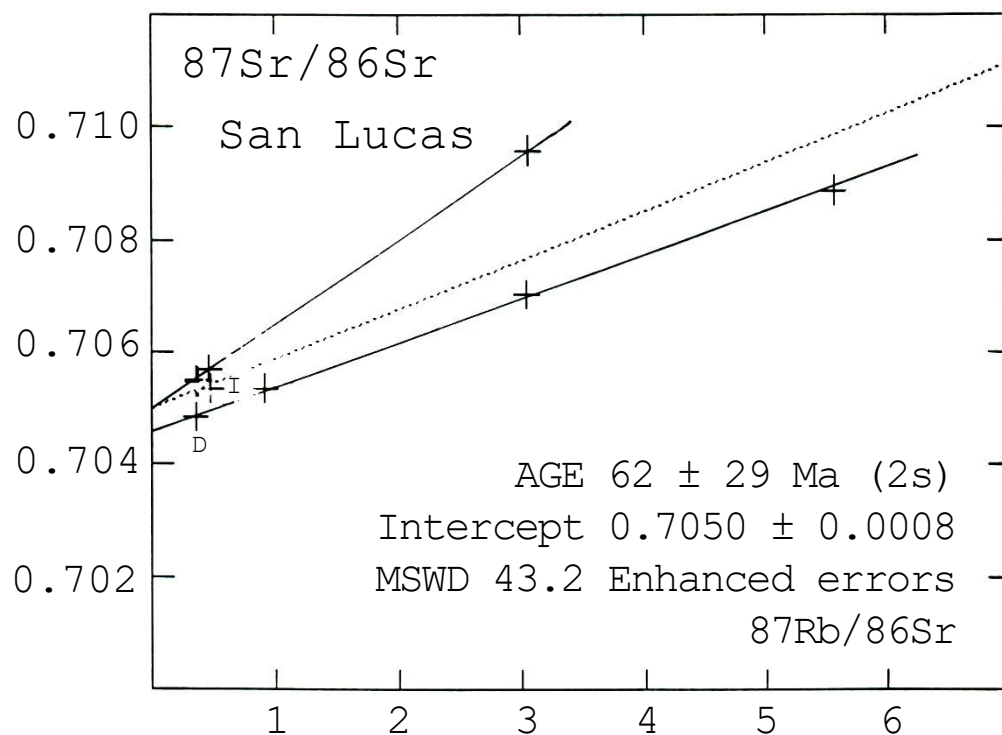


Figure 22. San Lucas – all samples

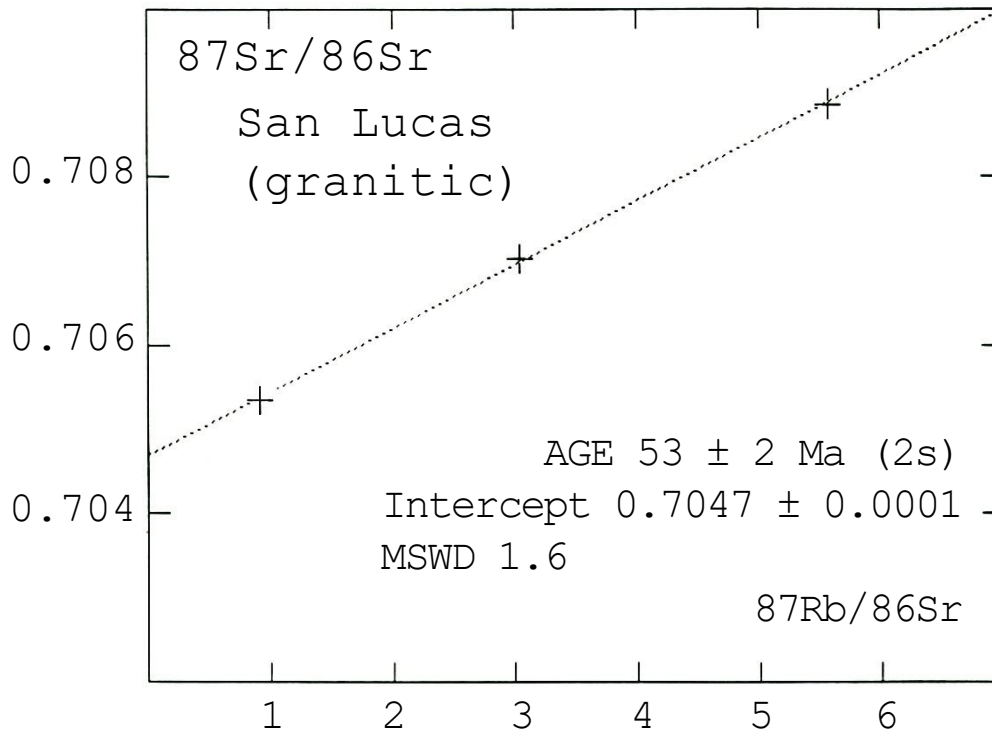


Figure 23. San Lucas – granitic samples only

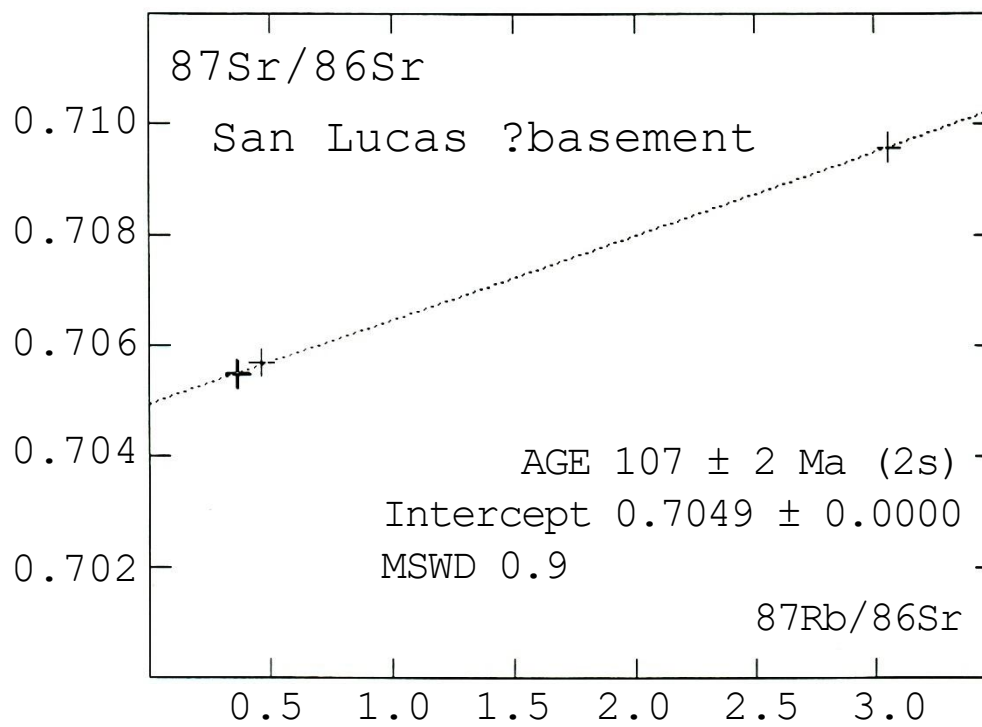


Figure 24. San Lucas – gneissic basement

13. San Lucas pluton (CCR/E/87/28A-I)

Nine samples of very fresh rock were collected along a road section and from the banks of the Río Tuntun. Although originally mapped as one pluton the present investigation revealed a wide variety of rock types; consisting of a coarse pink-feldspar porphyritic biotite-adamellite at the northern end, followed by more even medium-grained grey granodiorite, then a possible raft of basement gneiss, passing into more granodioritic material. When all the data are plotted together on the isochron diagram, they scatter widely (MSWD=543, Fig. 22), but apparently fall into two main groups. The data for the three adamellite samples (A, B & C) together form an isochron (MSWD=1.6, Fig. 23) with an age of 53 ± 2 Ma; $R_i=0.7047 \pm 1$, whereas those for samples E, F, G and H from the southern end of the traverse (including the two gneissic samples E and F) define another isochron (MSWD=0.99, Fig. 24) giving an age of 107 ± 2 Ma, $R_i=0.7049 \pm 1$. The data for sample D (a grey granodioritic variety taken from a loose boulder in the stream) lies close to the 53 Ma isochron whilst those for sample I (similar to D but from an outcrop at the extreme end of the traverse some ten kilometres away from the others and on the far side of a second 2Km-wide belt of basement gneisses) plots in an intermediate position between the two isochrons.

It is concluded that metamorphism affected the basement rocks in this area at around 107 Ma (early Cretaceous) and this was followed by igneous intrusion at about 53 Ma (early Tertiary). It is possible that the intrusive event partially reset the isotopic systems in sample I but apparently did not affect the other 'basement' samples. It would appear that the so-called basement gneisses in this area are much younger and unrelated to the migmatitic gneisses seen to the east at Sabanilla - but it would be more convincing if more samples had been taken, particularly from the other large exposure between samples H and I. It is hoped that further K-Ar analysis may confirm these conclusions and it is suggested that geochemical and Sm-Nd investigations may constrain the relationships of these rocks.

14. Conclusions

Many of the rock suites analysed in this study have yielded Rb/Sr data which scatter widely on the isochron diagrams. In view of the generally very uniform values for the calculated initial ratios from the best isochron data it is probably unlikely that this scatter is due to variable initial ratios in the various samples and more likely that it is due to later open system behaviour and disturbance of the isotopic systems. The sampling strategy - collecting suites over a restricted area - would also mitigate against variable initial ratio being the cause of the scatter (this may not be true, however, for samples from loose boulders in rivers).

Despite the efforts made to collect only fresh samples it is likely that in several cases the later disturbance may be due to recent weathering effects, but for the majority it would appear that later tectonic or hydrothermal events are the main cause. Many of the preferred ages are based on a small amount of selected data and should be treated with caution. Moreover, in disturbed systems, it is impossible to say, from the isochron data alone, whether the calculated age is closer to the original event or to that causing the disturbance. If the predominant effect is loss of radiogenic strontium (from rubidium lattice sites), or gain of rubidium, then the points will be displaced to the right and below the original line and the age will be lowered. Rb loss, however, will displace the points to the left and hence tend to increase the calculated age. Possibly a geochemical study could aid in the interpretation of the disturbed suites.

The calculated ages reveal a spectrum of apparent events ranging from Permian to Oligocene times and there is a hint that some of these bodies may have had significantly older precursors. In the north, the Chingual orthogneiss and Abitagua granite are recording ages around 160 Ma (mid Jurassic). In the latter this probably approximates to the time of emplacement but in the former may represent metamorphism; the low initial ratio and low Rb/Sr range suggesting a less evolved magma (geochemistry required here). The Azafrán intrusion, however, appears to be significantly younger than this (early Cretaceous).

The original age of the Peggy Mine blue-quartz granite cannot be deduced from the present data but there is a strong indication of metamorphism in the late Cretaceous; though it must be noted that this is based on scattered data for only three samples from loose boulders in a river and clearly requires further work before any firm conclusions can be drawn.

In the south, the main components of the Zamora batholith appear to be recording rather imprecise ages of around 240 Ma (Permian to Triassic) with a major early-Jurassic overprint (ca. 187 Ma for Napurca - the 166 Ma for the Río Pituca veins can only be considered as very approximate since it is essentially based on a two-point line). The Sabanilla migmatite data also appears to be reflecting this Permo-Triassic event but the Río Mayo pluton is significantly younger and does not seem to be related - though with such high errors it is difficult to assign this to a particular event.

In the extreme south the Portachuela pluton appears to be the youngest in this study (?Eocene/Oligocene) but the data are very poor and this cannot be considered to be a reliable age. The San Lucas pluton lies farther north, near to Sabanilla, and three samples of adamellitic material give an early Tertiary age whereas associated gneissic basement appears to be recording an early Cretaceous overprint - very different from Sabanilla and apparently unrelated to any other events in the area, except perhaps to that affecting the Peggy Mine granite.

The majority of samples appear to have initial ratios of around 0.704. This is very typical of many Andean plutonic rocks (e.g. the Peruvian coastal batholith) and indicates derivation directly from the mantle with only a small amount of interaction with crustal material.

C. C. Rundle 18/12/87

Table 3. Rb-Sr results for samples from Ecuador – 1987
(All samples numbers prefix CCR/E/87/..)

Intrusive	Sample No.	ppm Rb	ppm Sr	$^{87}\text{Rb}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$
Chingual gneiss	2A	37.7	470	0.2319	0.70432
	2B	38.2	467	0.2368	0.70414
	2C	44.4	353	0.3640	0.70450
	2D	46.3	335	0.3999	0.70460
	2E	31.6	517	0.1766	0.70406
	2F	30.6	507	0.1748	0.70402
	2G	31.2	507	0.1779	0.70413
	2H	47.3	487	0.2807	0.70408
	2I	44.7	417	0.3106	0.70428
	2J	46.6	405	0.3326	0.70433
Abitagua granite (North)	5A	159	22.7	20.42	0.75183
	5B	85.9	285	0.8717	0.70652
	5C	156	26.3	17.29	0.74410
	5D	87.0	259	0.9730	0.70677
	5E	160	23.4	19.85	0.74963
	5F	66.5	421	0.4574	0.70560
	5G	92.3	389	0.6868	0.70620
	5H	103	327	0.9044	0.70664
	5I	150	54.1	8.016	0.72298
Abitagua granite (South)	6A	117	353	0.9561	0.70692
	6B	132	428	0.8886	0.70667
	6C	116	85.2	3.951	0.71329
	6D	130	98.5	3.821	0.71348
	6E	160	105	4.449	0.71563
	6F	169	88.2	5.523	0.71788
	6G	225	15.2	43.31	0.80394
	6H	102	355	0.8319	0.70670
	6I	93.1	382	0.7041	0.70615
	6J	235	10.3	67.85	0.86170
	6K	54.9	959	0.1659	0.70494
Azafrán granodiorite	8A	100	86.5	3.345	0.71029
	8B	127	70.8	4.817	0.71291
	8C	6.0	52.6	0.3316	0.70669
	8D	109	77.1	4.074	0.71160
	8E	110	75.5	4.229	0.71171
	8F	111	71.0	4.495	0.71223
	8G	111	80.5	3.984	0.71147
	8H	104	60.3	5.004	0.71309
	8I	106	42.4	7.221	0.71376
Río Verde complex	10A	66.7	444	0.4346	0.70606
	10B	72.3	442	0.4724	0.70613
Peggy Mine blue quartz granite	14A	144	110	3.801	0.72216
	14B	33.3	259	0.3716	0.70393
	14C	144	152	2.758	0.72077
	14D	142	101	4.081	0.72220
Napurca granodiorite – Zamora (North-West)	16A	54.7	251	0.6310	0.70664
	16B	56.9	248	0.6621	0.70704
	16C	52.5	236	0.6409	0.70667
	16D	82.6	46.2	5.1900	0.71840
	16E	46.7	247	0.5469	0.70609
	16F	51.1	238	0.6231	0.70622
	16G	14.9	374	0.1160	0.70499
	16H	26.1	270	0.2802	0.70530

Table 4. Rb-Sr results for samples from Ecuador – 1987

Intrusive	Sample No.	ppm Rb	ppm Sr	$^{87}\text{Rb}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$
Zamora (North-East)	21A	66.2	391	0.4904	0.70631
	21B	70.7	367	0.5582	0.70665
	21C	67.6	285	0.6872	0.70713
	21D	63.9	432	0.4281	0.70629
	21E	79.1	391	0.5844	0.70668
	21F	96.7	339	0.8275	0.70734
	21G	62.8	364	0.4992	0.70635
	21H	91.2	336	0.7820	0.70648
	21I	64.8	349	0.5387	0.70679
	21J	132	257	1.4870	0.70822
Río Pituca – Zamora (South)	22A	105	373	0.8170	0.70660
	22B	71.8	181	1.1390	0.70770
	22C	103	387	0.7701	0.70645
	22D	107	385	0.8054	0.70649
	22E	96.8	388	0.7213	0.70640
	22F	59.2	674	0.2545	0.70460
	22G	145	97.9	4.2720	0.71403
	22H	146	98.9	4.2430	0.71410
Sabanilla migmatite	23A	123	204	1.747	0.71788
	23B	110	197	1.601	0.71774
	23C	45.2	201	0.6521	0.71436
	23D	128	208	1.768	0.71776
	23E	119	210	1.633	0.71682
	23F	128	192	1.931	0.71716
	23G	96.3	231	1.205	0.71546
	23H	121	124	2.833	0.72173
Río Mayo pluton	26A	58.6	329	0.5161	0.70617
	26B	56.0	335	0.4848	0.70612
	26C	53.5	325	0.4763	0.70599
	26D	47.3	359	0.3821	0.70592
	26E	42.4	353	0.3476	0.70578
Portachuela pluton	27A	52.9	738	0.2074	0.70473
	27B	66.6	290	0.6639	0.70493
	27C	64.1	354	0.5248	0.70499
	27D	68.8	336	0.5924	0.70582
	27E	61.1	340	0.5192	0.70518
	27F	121.8	60.8	5.792	0.70760
	27G	57.4	358	0.4641	0.70499
San Lucas pluton	28A	130	123	3.049	0.70703
	28B	154	79.9	5.561	0.70887
	28C	82.2	263	0.9165	0.70536
	28D	37.9	310	0.3547	0.70484
	28E	60.4	478	0.3654	0.70549
	28F	67.1	525	0.3691	0.70547
	28G	115	108	3.060	0.70959
	28H	74.6	465	0.4642	0.70568
	28I	68.1	410	0.4800	0.70534

Table 5. Summary of samples collected for the Geochronology Program, Ecuador-1987. All samples numbers prefix CCR/E/87/..

No.	Letter	Quantity	Intrusive	Method/Mineral
1	(A – C)	(3)	Pimampiro diorite	5 K-Ar [2(Hb + Bt) + Mosc]
2	(A – J)	(10)	Chingual orthogneiss / foliated granodiorite	10 Rb-Sr + 4 K-Ar [Bt + (Mosc + Bt + ?Hb)]
3		(1)	Sacha orthogneiss	2 K-Ar [Hb + Bt]
4		(1)	Papallacta amphibolite dyke	2 K-Ar [Hb + Bt]
5	(A – I)	(9)	Abitagua granite (North)	9 Rb-Sr + 2 K-Ar [Hb + Bt]
6	(A – K)	(11)	Abitagua granite (South)	11 Rb-Sr + 4 K-Ar [2(Hb + Bt)]
7		(1)	Andesitic dyke cutting Abitagua	1 K-Ar [Hb]
8	(A – I)	(9)	Azafrán tonalite	9 Rb-Sr + 2 K-Ar [Hb + Bt]
9		(1)	Azafrán Bt rich vein	1 K-Ar [Bt]
10	(A – B)	(2)	Río Verde complex	2 Rb-Sr + 4 K-Ar [2(Hb + Bt)]
11	(B – E)	(4)	Agoyán garnet-mica schists/gneiss	8 Sm-Nd + 4 K-Ar [4Mosc]
12	(A – C)	(3)	Pungalá granodiorite	6 K-Ar [3(Hb + Bt)]
13	(A – C)	(3)	Magtayán diorite	4 K-Ar [(Hb + Bt) + 2Hb]
14	(A – D)	(4)	Peggy Mine blue quartz granite	4 Rb-Sr + 2 K-Ar [2Bi]
15	(A – B)	(2)	Paute volcanics	2 K-Ar [2Hb]
16	(A – H)	(8)	Napurca granodiorite (Zamora-West)	8 Rb-Sr + 4 K-Ar [2(Hb + Bt)]
17		(1)	Napurca area gabbro	1 K-Ar [Hb]
18		(1)	Napurca area andesite	1 K-Ar [Hb]
19		(1)	Napurca area granodiorite	2 K-Ar [Hb + Bt]
20		(1)	Napurca area granodiorite	2 K-Ar [Hb + Bt]
21	(A – J)	(10)	Zamora (East)	10 Rb-Sr + 4 K-Ar [2(Hb + Bt)]
22	(A – H)	(8)	Río Pituca (Zamora South)	8 Rb-Sr + 4 K-Ar [(Hb + Bt) + 2Hb]
23	(A – H)	(8)	Sabanilla migmatite	8 Rb-Sr + 4 K-Ar [2Bi + (Bt + Mosc)]
24	(A – D)	(4)	Valladolid dyke + pegmatite cutting basement gneiss	5 K-Ar [2Mosc + Bt + (Hb + Bt)]
25		(1)	Río Mayo dyke cutting pluton	1 K-Ar [Hb]
26	(A – E)	(5)	Río Mayo pluton	5 Rb-Sr + 5 K-Ar [2(Hb + Bt) + Bt]
27	(A – G)	(7)	Portachuela pluton	7 Rb-Sr + 5 K-Ar [(Hb + Bt) + 3Bi]
28	(A – I)	(9)	San Lucas pluton	9 Rb-Sr
29	(A – B)	(2)	Catamayo pluton	2 K-Ar [2Bi]

TOTAL: 130 samples; 12 isochrons Rb-Sr (98 samples); 74 K-Ar; 8 Sm-Nd [4(wr + garnet)]

Table 6. Samples collected for the Geochronology Program, Ecuador-1987. All samples numbers prefix CCR/E/87/..

SAMPLE No.	No. OF BAGS	SECTOR	COORDINATES	SHEET	FINE POWDER	MINERAL SEPARATION	OBSERVATIONS
1A	1	Río Mataquí		Pimampiro (c)	×	✓ Hb + Bt	
1B	1	Río Mataquí bridge		Pimampiro (c)	×	✓ Mosc	boulders/blocks
1C	1	Q. Manzanal		Pimampiro (c)	×	✓ Hb + Bt	
2A	2		8875-100615	Huaca	✓	×	waterfall
2B	2		8875-100615	Huaca	✓	×	waterfall
2C	2		8869-100605	Huaca	✓	✓ Bt	500 m before waterfall
2D	2		8869-100605	Huaca	✓	×	500 m before waterfall
2E	2		8881-100638	Huaca	✓	✓ Mosc + Bt + Hb	waterfall
2F	2		8881-100638	Huaca	✓	×	waterfall
2G	2		8881-100638	Huaca	✓	×	waterfall
2H	2		8881-100638	Huaca	✓	×	waterfall
2I	2		8872-100630	Huaca	✓	×	
2J	2		8874-100615	Huaca	✓	×	
3	2	Quebrada Tungurahua	8841-100699	Huaca	×	✓ Hb + Bt	
4	2	Papallacta	8183-9598	Papallacta	×	✓ Hb + Bt	settlement
5A	2		857-9282	Cosanga	✓	×	Guacamayos Cordillera
5B	2		857-9282	Cosanga	✓	×	Guacamayos Cordillera
5C	2		857-9282	Cosanga	✓	×	Guacamayos Cordillera
5D	2		857-9282	Cosanga	✓	×	Guacamayos Cordillera
5E	2		857-9282	Cosanga	✓	×	Guacamayos Cordillera
5F	2		8555-9286	Cosanga	✓	×	Guacamayos Cordillera
5G	2		8555-9286	Cosanga	✓	✓ Hb + Bt	Guacamayos Cordillera
5H	2		854-9286	Cosanga	✓	×	Guacamayos Cordillera
5I	1		854-9286	Cosanga	✓	×	Guacamayos Cordillera
6A	3	P. Huagmayacu	8131-8441	Mera (c)	✓	✓ Hb + Bt	Cashurcu sector
6B	2	P. Huagmayacu	8131-8441	Mera (c)	✓	×	Cashurcu sector
6C	2	S. Abitagua	8147-8404	Mera (c)	✓	×	cut on the new road to Baños
6D	2	S. Abitagua	8148-8405	Mera (c)	✓	×	cut on the new road to Baños
6E	2	R. Zúñag	8127-8444	Mera (c)	✓	×	± 80 m before the bridge
6F	2	R. Zúñag	8127-8444	Mera (c)	✓	×	± 80 m before the bridge
6G	1	R. Zúñag	8127-8444	Mera (c)	✓	×	under the Río Zúñag bridge
6H	2	R. Zúñag	8127-8444	Mera (c)	✓	×	left bank

Table 7. Samples collected for the Geochronology Program, Ecuador-1987. All samples numbers prefix CCR/E/87/..

SAMPLE No.	No. OF BAGS	SECTOR	COORDINATES	SHEET	FINE POWDER	MINERAL SEPARATION	OBSERVATIONS
6I	2	R. Zúñag	8127-8444	Mera (c)	✓	×	
6J	2	R. Zúñag	8127-8444	Mera (c)	✓	×	
6K	2	R. Zúñag	8127-8444	Mera (c)	×	✓	Hb + Bt past the bridge/Baños
7	1			Mera (c)	×	✓	Hb
8A	2	El Rosario	8050-8448	Baños (c)	✓	×	Quebrada, block
8B	2	El Rosario	8049-8445	Baños (c)	✓	×	
8C	1	El Rosario	8049-8445	Baños (c)	✓	×	
8D	2	Hcda. San Vicente	8045-8444	Baños (c)	✓	×	
8E	2		8042-8444	Baños (c)	✓	✓	Hb + Bt
8F	2		8039-8449	Baños (c)	✓	×	quarry
8G	2	Hcda. San Vicente	8045-8444	Baños (c)	✓	×	
8H	2		8039-8449	Baños (c)	✓	×	
8I	1		8039-8449	Baños (c)	✓	×	quarry
9	1		8039-8449	Baños (c)	×	✓	Bt quarry
10A	1	Río Verde	8009-8451	Baños (c)	×	✓	Hb + Bt
10B	1	Río Verde	8009-8451	Baños (c)	×	✓	Hb + Bt right bank river outcrop
11B	1	Agoyán	7939-8458	Baños (c)	✓	✓	Garn + Bt + Mosc Old tunnel / exit
11C	1	Agoyán	7939-8458	Baños (c)	✓	✓	Garn + Bt + Mosc Old tunnel / exit
11D	1	R. Pastaza	7918-8458	Baños (c)	✓	✓	Garn + Bt + Mosc Bridge ± 50 m
11E	1	R. Pastaza	7918-8458	Baños (c)	✓	✓	Garn + Bt + Mosc Bridge ± 50 m
12A	1		680-965	Guamote (t)	×	✓	Hb + Bt
12B	1		6801-9666	Guamote (t)	×	✓	Hb + Bt
12C	1		680-9800	Riobamba (t)	×	✓	Hb + Bt Alao power station/EER
13A	1	Laguna Cubillín	678-9758	Totoras (t)	×	✓	Hb + Bt
13B	1	R. Osogochi	679-9759	Totoras (t)	×	✓	Hb block
13C	1		621-9514	Totoras (t)	×	✓	Hb block
14A	2	Peggy Mine	4765-5768	Sigsig	✓	✓	Bt boulders/blocks
14B	1	Peggy Mine	4765-5768	Sigsig	✓	×	boulders/blocks
14C	1	Peggy Mine	4761-5769	Sigsig	✓	×	boulders/blocks
14D	2	Peggy Mine	4761-5769	Sigsig	✓	✓	Bt
15A	1	R. San Francisco	5545-7300	Córdova (c)	×	✓	Hb boulders/blocks from the Paute
15B	1	R. San Francisco	5545-7300	Córdova (c)	×	✓	Hb Formation?

RB/vec. 87.06.08

Table 8. Samples collected for the Geochronology Program, Ecuador-1987. All samples numbers prefix CCR/E/87/..

SAMPLE No.	No. OF BAGS	SECTOR	COORDINATES	SHEET	FINE POWDER	MINERAL SEPARATION	OBSERVATIONS
16A	2	Jimbuena	3621-8639	Yantzaza	✓	×	Hornblende granodiorite
16B	2	Jimbuena	3675-8661	Yantzaza	✓	×	Aplite dyke
16C	2	Jimbuena	3690-8534	Yantzaza	✓	✓ Hb + Bt	Granodiorite
16D	1	Jimbuena	3690-8534	Yantzaza	✓	×	Felsite dyke
16E	2	Jimbuena	3691-8531	Yantzaza	✓	×	Granodiorite?
16F	2	Chapintza	3692-8440	Yantzaza	✓	×	Xenoliths
16G	2	Chapintza	3692-8440	Yantzaza	✓	×	Boulders
16H	2	Chapintza	3692-8440	Yantzaza	✓	✓ Hb + Bt?	Boulders
17	1	Chapintza	3692-8440	Yantzaza	×	✓ Hb	Boulders from Q. Curishpe
18	1	Chapintza	3692-8440	Yantzaza	×	✓ Hb	Boulders from Q. Curishpe
19	2	Q. Maycunantza	3509-8299	Yantzaza	×	✓ Hb + Bt	Zamora batholith?
20	1	El Vergel	3398-7842	Yantzaza	×	✓ Hb + Bt	Zamora batholith?
21A	2	El Cóndor	6598-5302	Guaysimi	✓	✓ Hb + Bt	Biotite and hornblende granodiorite or tonalite
21B	2	El Cóndor	6598-5302	Guaysimi	✓	×	
21C	1	El Cóndor	6598-5302	Guaysimi	✓	×	Felsite
21D	1	El Cóndor	6598-5302	Guaysimi	✓	×	
21E	2	Q. Chapintza	6578-5320	Guaysimi	✓	×	Granodiorite
21F	2	Q. Chapintza	6551-5329	Guaysimi	✓	×	Granodiorite
21G	2	Q. Chapintza	6535-5426	Guaysimi	✓	✓ Hb + Bt	Hornblende granodiorite
21H	2	Q. Chapintza	6535-5426	Guaysimi	✓	×	Granite boulder
21I	2	Q. Chapintza	6535-5426	Guaysimi	✓	×	Granodiorite?
21J	1	Q. Chapintza	6535-5426	Guaysimi	✓	×	Dacite?
22A	2	Q. La Pituca	2941-4277	Zamora	✓	×	Granodiorite boulders with hornblende and biotite
22B	2	Q. La Pituca	2941-4277	Zamora	✓	✓ Hb + Bt	
22C	2	Q. La Pituca	2941-4277	Zamora	✓	×	
22D	2	Q. La Pituca	2941-4277	Zamora	✓	×	
22E	2	Río Jambué	2885-4321	Zamora	✓	✓ Hb	Granodiorite and tonalite boulders
22F	2	Río Jambué	2885-4321	Zamora	✓	✓ Hb	
22G	2	Río Jambué	2885-4321	Zamora	✓	×	
22H	2	Río Jambué	2885-4321	Zamora	✓	×	
23A	2	El Consuelo	1990-5870	Loja Norte	✓	×	Biotite gneiss
23B	2	El Consuelo	1990-5870	Loja Norte	✓	×	Aphanitic gneiss?
23C	1	El Consuelo	1985-5940	Loja Norte	✓	×	Mafic xenolith
23D	2	El Consuelo	1985-5940	Loja Norte	✓	✓ Bt	Gneiss
23E	2	El Consuelo	1970-6000	Loja Norte	✓	✓ Bt + Mosc	Migmatitic gneiss

Table 9. Samples collected for the Geochronology Program, Ecuador-1987. All samples numbers prefix CCR/E/87/..

SAMPLE No.	No. OF BAGS	SECTOR	COORDINATES	SHEET	FINE POWDER	MINERAL SEPARATION	OBSERVATIONS
23F	2	El Consuelo	1970-6000	Loja Norte	✓	✓ Bt	Gneiss
23G	2	El Consuelo	1970-6000	Loja Norte	✓	×	Gneiss
23H	2	El Consuelo	1978-6325	Loja Norte	✓	×	Gneis biotítico
24A	1	Valladolid	0794-9825	Valladolid	×	✓ Hb + Bt	Amphibolite
24B	1	Valladolid	0794-9825	Valladolid	×	✓ Mosc	Muscovite schist
24C	1	Cruceros	0804-9355	Valladolid	×	✓ Mosc	Muscovite schist
24D	1	Palanda	0699-8672	Valladolid	×	✓ Bt	Biotite granite?
25	1	Loma Pucarón	0739-8094	Río Mayo	×	✓ Hb	Diorite
26A	2	Loma Pucarón	0732-8039	Río Mayo	✓	×	Granodiorite
26B	2	Loma Pucarón	0732-8039	Río Mayo	✓	✓ Hb + Bt	Granodiorite
26C	2	Polanuma	0775-7921	Río Mayo	✓	✓ Hb + Bt	Granodiorite with biotite + hornblende
26D	2	Polanuma	0770-7852	Río Mayo	✓	×	Granodiorite o diorite?
26E	2	Polanuma	0741-7810	Río Mayo	✓	✓ Bt	Granodiorite
27A	2	Q. 25 de diciembre	7770-7208	Laguna Cox	✓	✓ Bt	Felsic intrusive
27B	2	Q. 25 de diciembre	7739-7235	Laguna Cox	✓	×	Granodiorite
27C	2	Q. Venado	7555-7445	Laguna Cox	✓	✓ Bt + Hb?	Granodiorite block
27D	2	Q. Venado	7530-7461	Laguna Cox	✓	×	Granodiorite
27E	2	Suquilanda	7475-7525	Laguna Cox	✓	×	Granodiorite block
27F	2	Suquilanda	7465-7565	Laguna Cox	✓	✓ Bt	Granodiorite block
27G	2	Suquilanda	7451-7665	Laguna Cox	✓	✓ Bt	Granodiorite
28A	2	Q. Tuntún	9325-8488	Santiago	✓	×	Microgranite
28B	2	Q. Tuntún	9325-8488	Santiago	✓	×	Aplite dyke
28C	2	Vinuyacu	9359-8464	Santiago	✓	×	Granite boulder
28D	2	Vinuyacu	9368-8452	Santiago	✓	×	Granite boulder
28E	2	Durazno	9421-8271	Las Juntas	✓	×	Granodiorite?
28F	2	Gualán	9448-8200	Las Juntas	✓	×	Granodiorite
28G	1	Gualán	9448-8200	Las Juntas	✓	×	Basic dyke?
28H	2	La Chorrera	9469-8161	Las Juntas	✓	×	Granodiorite?
28I	2	El Gallo	9858-7521	Loja Norte	✓	×	Granodiorite?
29A	1	Catamayo	9110-5971	La Toma	×	✓ Bt	Biotite granite
29B	1	Catamayo	9139-5992	La Toma	×	✓ Bt	Biotite granite

Bt = biotite; Hb = hornblende; Mosc = muscovite; Garn = garnet; wr = whole rock

✓ = Yes; × = No

APPENDIX 4

Heavy mineral analysis of samples from the Río Mulatos

by

R. Ixer (Aston University, UK)

Study sponsored by BP Minerals Int.

Ecuador Mineral Concentrates

37P-46P y 37F-48F

Describe the opaque mineralogy of material using x16 oil immersion lenses. Investigate the presence or absence of gold and P.G.M. and if present, comment on size and distribution. Examine the garnets and discuss their origin.

Summary

No gold greater than 5 μm in diameter was recognised in polished blocks from any of the samples. No P.G.M. nor possible P.G.M. were seen in any sample. Gold (1-5 μm) within arsenopyrite was seen in samples 41P and 43P and in their panned concentrates.

1. Method for opaque petrography

One polished block, 30 mm diameter, was made of all samples. Blocks of all coarse material (37P-46P) and 47F and 48F were investigated at x8, x16 and x40 oil, all fine samples (37F-46F) were investigated at x8 and x16 oil. Especial care was taken to discover the presence of small native metal inclusions in pyrrhotite, arsenopyrite, galena and molybdenite; and the nature of the sulphide inclusions in magnetite. It was found that using x40 oil added little to the mineralogical characterization obtained from x16 oil although the presence of gold and ?Bi traces in arsenopyrite were only seen at x40 (RAI).

2. Results of opaque petrography

The results are tabulated in Table 1 (200 mesh samples) and Table 2 (80-mesh samples).

Generally, only the presence or absence of species were noted, for the major opaque minerals no relative abundances were attempted.

Comparison of the results for the 200 mesh and 80 mesh (37-46) showed that a number of potentially interesting minerals (including arsenopyrite, galena and molybdenite) were missing from the 80 mesh but present in the 200-mesh sample. Namely that, discrete grains ($> 40 \mu\text{m}$) of arsenopyrite were seen in 38P, 40P, 41P and 46P but not in their 80-mesh equivalent sample; galena in 41P, 43P and 46P, and molybdenite in 43P but not in their 80-mesh equivalent. However, identical results were found for samples 37, 39, 42, 44 and 45.

Only in samples 43P and 44P were opaques more abundant than non-opaques. In all 80 mesh samples opaques were subordinate to non-opaque phases.

In samples 37P, 37F, 47F and 48F opaque oxides were more abundant than sulphides. In samples 38P, 39P, 45P, 43F and 46F the opaques and sulphides were approximately equal in amounts. In all other samples (200 mesh) pyrite/sulphides were more abundant than opaque oxides. Within most of the 80 mesh samples the opaque content was too small to make a reasonable estimate.

Tables 1 and 2 list the mineral species which were recognized but given no account of their relative abundances, however where the presence of a phase is indicated, it denotes a discrete grain > 40 µm in diameter. Small inclusions 5-20 µm are noted with their host mineral. A wide variety of semi-opaque phases which are assumed to include metamorphic silicates or sphene-like phases have not been described, but are common.

Amongst the sulphides, pyrite dominates. Pyrrhotite ≥ chalcopyrite/arsenopyrite (1-5 grains/section) > (1-<5 grains/section)/sphalerite ≥ molybdenite (1 large grain). Amongst the oxides magnetite and its oxidation products ≥ ilmenite + alteration products. Haematite is abundant and, in some sections, dominates. Sphene, TiO₂ minerals and limonite are common.

A brief description of the occurrence of each phase is given, based upon their 200 mesh fraction plus 47 and 48F. No paragenetic sequence is suggested by this order.

2.1 Sulphides

2.1.1 Pyrite

Pyrite is the dominant sulphide in all the samples. The vast majority of grains are coarse single crystals which are fresh or oxidized to limonite; some of the oxidation is extensive, however, most are unaltered except for 48F. Mosaics of smaller pyrite crystals are seen, and small framboids or pyritohedral crystals (10-30 µm) within rock clasts are present in 46P but especially in 45P where framboidal pyrite associated with graphite is common. The coarse-grained pyrite crystals are both inclusion-free or contain base-metal sulphide inclusions especially pyrrhotite and chalcopyrite ± cubanite and to a lesser extent sphalerite and galena. Pyrite as an alteration product after pyrrhotite is seen in all samples except 47 and 48F (where little pyrite is present).

Pyrite does not carry discrete gold but small 5 µm ?native bismuth grains in pyrite were seen in 40P, 44P and 46P.

2.1.2 Pyrrhotite

Discrete grains are present in all samples except 44P, 45P, 47F and 48F. These discrete grains are inclusion-free, can be fresh or altered to 'zwischen-produkt', pyrite-marcasite intergrowths (including birds eyes) to pyrite-magnetite intergrowths or to limonite.

Small crystals (10-30 µm), often with small pentlandite flames (1-3 µm) and ?millerite (2-5 µm) occur associated with chalcopyrite in ?metamorphic silicates. Pyrrhotite is intergrown with pyrite and with arsenopyrite and occurs as inclusions in arsenopyrite. The latter association (pyrrhotite-arsenopyrite) occurs as part of a number of gold-bearing arsenopyrite deposits throughout the world.

Pyrrhotite inclusions (1-30 µm) and pyrrhotite-chalcopyrite mixed inclusions in pyrite are present in all samples, pyrrhotite is also found within magnetite in all samples except 42P, 44P, 46P and 47F.

2.1.3 Marcasite

It is present as an alteration product of pyrrhotite, and is present in all samples except for 37P (although is present in 37F), 47F and 48F. It forms bladed intergrowth with pyrite (NPM in table 1), as fine mosaics or as rims about pyrrhotite ('after po' in Table 1).

2.1.4 Chalcopyrite

Coarse discrete crystals were seen in all samples except 37P, 45P and 48F where it is present only as small inclusions in pyrite or silicate. Coarse crystals are inclusion-free and are oxidized to limonite, although many are fresh. It is commonly intergrown with pyrite, or is associated with pyrrhotite as small crystals in silicate 'gangue' (37, 38, 39, 40, 43 and 44P).

It is very common as small (5-30 μm) inclusions in pyrite either above or intergrown with pyrrhotite, with cubanite/mackinawite, with sphalerite, or any combination of these. It also occurs as small inclusions in magnetite (37, 38, 39 43 and 44P). Alteration of chalcopyrite to other sulphides is uncommon, but bornite and covellite replacing chalcopyrite are present in 43P.

2.1.5 Sphalerite

Discrete sphalerite grains (between 1-5 grains) are present in 39, 45 and 46 where it has fine-grained chalcopyrite-disease. It shows internal reflection from light to dark brown. It is present as small inclusions within pyrite either alone, or intergrown with pyrrhotite, chalcopyrite and galena. Alteration of sphalerite to covellite is rare.

2.1.6 Galena

Discrete coarse-grained galena is present in 41, 42, 43 and 46P (between 1-5 grains) where it is inclusion-free and unaltered except for 46 where minor replacement of galena by ?cerussite is present. It is intergrown with chalcopyrite in 41 within a silicate gangue. It occurs as small inclusions within pyrite in specimens 39-46 either along or intergrown with pyrrhotite, or sphalerite and chalcopyrite.

2.1.7 Arsenopyrite

Discrete white arsenopyrite carries pyrrhotite inclusions in 39, 40, 41 and 43P, is inclusion free in 38 and 42P. It has a definite association with pyrrhotite and can be seen to be intergrown with it.

A 'pink' arsenopyrite intergrown with white arsenopyrite is present in 41 and 43. White arsenopyrite in 43P carries 1 grain $6 \times 1 \mu\text{m}$ in size of a high reflectance pale yellow phase which may be electrum. Pink arsenopyrite in 41P carries $1 \mu\text{m}$?electrum inclusions (≈ 5 grains close to $1 \mu\text{m}$?galena/bismuth and $2 \mu\text{m}$?bismuthinite inclusions).

2.1.8 Molybdenite

One grain of molybdenite is present 43P and is inclusion-free. 40 and 42 small ($\approx 20 \mu\text{m}$ in length) molybdenite occurs in pyrite or silicate close to pyrite.

2.1.9 Copper-iron sulphides, copper sulphides

A single coarse-grained crystal of "idaite" is present in 42P where it is altering to covellite. Bornite in trace amounts replaces chalcopyrite in 39 and 43P. Cubanite is commonly intergrown with chalcopyrite as small inclusions in pyrite. Covellite replaces chalcopyrite and sphalerite but is rare.

In 43P rare 20-40 µm diameter grains of an unknown, low reflectance highly anisotropic phase could be a copper-selenide.

2.1.10 Tetrahedrite group mineral

A single grain 20 µm of tetrahedrite associated with chalcopyrite is present in pyrite in 42P.

2.2 Oxides

2.2.1 Magnetite

Coarse-grained, often euhedral, magnetite is both fresh or highly oxidized, often both extremes are found in the sample. Magnetite with blue haematite rims and white haematite as martite is common, alteration to TiO₂ phases is rarer. Magnetite with oxidation lamellae of ilmenite is present in 37 and 38P. Magnetite with ?pleonaste lamellae which has further oxidized to martite is present in 37, 38, 40, 41, 43, 44P and 47F.

Small euhedral magnetite within lava clasts is extensively oxidized to haematite especially in 39P.

Minor amounts of ?non-magmatic magnetite is intergrown with ilmenite in silicates, or occurs within pyrite as part of the alteration of pyrrhotite. Magnetite encloses small inclusions of pyrrhotite, chalcopyrite or mixed pyrrhotite-chalcopyrite. In 39P trace amounts of arsenopyrite and bornite occur within magnetite.

No gold nor P.G.M. were seen associated with magnetite.

2.2.2 Ilmenite

Coarse ilmenite is present, it contains abundant silicate inclusions in 38-40P, 42, 43 and 46P. Ilmenite is rare in 45P. Ilmenite-haematite solid solution (ilmeno-haematite and haemo-ilmenite) is present in minor amounts in all samples except 45P. Magnetite carries oxidation exsolution lamellae of ilmenites but this is minor.

Ilmenite as small laths often with rims of sphene are common within ?metamorphic silicates (except for 45P). Ilmenite is both fresh and extensively oxidized to haematite and TiO₂.

Sulphide inclusions are uncommon, but pyrrhotite and chalcopyrite are present in some ilmenites.

No gold or P.G.M. minerals were seen associated with ilmenite.

2.2.3 Hematite

Primary haematite is associated with ilmenite as solid-solution and exsolution intergrowths. Secondary haematite is abundant, as martite after magnetite or intergrown with TiO_2 after ilmenite. Coarse-grained haematite laths are present in 37, 39, 41, 42, 44 and 46P. Fine-grained haematite within rock fragments or replacing pyrite is common in 46P, 47F and 48F but especially in 45P.

One grain of botryoidal haematite is present in 43P.

2.2.4 Spene and TiO_2

Both are common alteration products after ilmenite and to a lesser extent, magnetite. TiO_2 also is found as inclusions in pyrite, and associated with fine-grained pyrite, haematite and graphite in rock fragments in 45P. Spene forms rims around ilmenite or occurs as discrete crystals in metamorphic silicates including ?garnet. 38P, 39P have very coarse-grained single crystals of ?rutile (1-4 grains/section) - these are probably rutile but could be wolframite/columbite.

2.2.5 Cassiterite?

If cassiterite be present it shows none of its characteristic features (single twins, strong anisotropy, inclusions of wolframite $\pm$ columbite). However, in 37P and 37F rare grains with the optical properties of cassiterite were seen (both specimens were done 'blind' so the coincidence may be significant). In 40P rare crystals have the habit of cassiterite.

2.2.6 Chromite

In 47F and 48F a single crystal of magnetite showed a low reflectance core suggesting it is chromium-rich. One grain of chromite with a ferrochromit rim was seen in 47F.

2.2.7 Limonite

This extensively replaces pyrite (especially 48F) pyrrhotite and chalcopyrite. It is commonly very banded.

No gold is seen associated with limonite.

2.3 Graphite

Graphite associated with metamorphic silicates or rock fragments is present in all samples but 39, 41, 47F and 48F (the last two have no graphite). It is associated with sedimentary rocks/metasediments in 40, 43, 45 and 46. In 45P it is abundant and is associated with framboidal pyrite.

2.4 Silicates

Garnet (optically identified in reflected light) is present as snowball garnets with trails of spene within it, in 37P-43P and 46P but is absent in 45P, 47F and 48F. Very zoned silicate, assumed to be garnet, is present in 35-41P, 43, 44 and 46P, it is absent in 45P, 47F and 48F. It was not recognised in 37P, 38P nor 42P. Euhedral unzoned garnet may also be present but was not looked for systematically.

2.5 Native metals

Trace amounts of white native metal are present in all specimens as 1-10 μm diameter grains (mainly $< 5 \mu\text{m}$) within *araldite*. It is believed to be adventitious especially as it is more abundant close to the edges of the section.

2.5.1 Bismuth?

2-5 μm diameter grains of a white-cream metal is present in pyrite in 40P, 44P and 46P. In 40P it may be associated with 2 μm ?bismuthinite.

2.5.2 Gold?

Trace amounts of a light-yellow metal gold or brass is present in all samples, of 1-10 μm in diameter, where it is found in the resin or in fractures within silicates and may be contamination.

2.5.3 Electrum?

It is present within arsenopyrite in 41P (1 μm) and in 43P (6 μm).

Cassiterite may be under-reported in the above description and perhaps wolframite, columbite and scheelite are present but not recognised - if they are present, they are in minor amounts. Sphene has been used for sphene plus epidote-group and some TiO_2 and scheelite (if present).

All other opaque minerals have been identified.

3. Method for panned concentrates

Each of the coarse concentrates (samples 38P to 46P) was reduced by careful panning with Teepol added to the panning water to avoid the loss of "skim and flow" gold. The reduced concentrates were then examined under a binocular microscope at x20 magnification. During microscopic examination a representative suite of garnets were removed for qualitative EDS analysis on a scanning electron microscope (Jon Naden).

3.1 Mineralogy

Much is tabulated in Table 3.

3.1.1 Major mineralogy

3.1.1a Garnets

Three types of garnet were identified: (i) an orange to pale orange translucent euhedral garnet; (ii) a black to smokey grey, opaque to translucent euhedral garnet and (iii) a rounded opaque red garnet with inclusions visible on the surface of the grains. Chemically types (i) and (ii) are indistinguishable and are: grossular-andradites with varying amounts of spessartine (Mn component). Type (iii) garnets are pyrope-almandines. In samples 37P to 44P the proportion of type (i) and (ii) (grossular-andradite) garnets is very much greater than type (iii) (pyrope-almandines) garnets. In samples 45P, 47F and 48F both types of garnet are rare and in 46P orange garnets are of much greater abundance than red garnets. In all samples except 44P and 45P garnets are a major component of the pan concentrate.

Sixty qualitative analyses of hand-picked garnets were made for all samples except 45P, 47F and 48F where too few garnets were collected. The majority of the analyses showed that a Ca, Fe, Mn, Al-bearing garnet belonging to the grossular-andradite series was the more abundant. Ca-poor garnets of the pyrope-almandine series were positively identified in 40, 41, 43 and 46P.

3.1.1b Sulphides

In samples 37P-40P, 47 and 48F sulphides are rare, and in samples 41P to 46P sulphides are dominant in the assemblage. The commonest sulphides are pyrite and pyrrhotine which are present in all samples. Chalcopyrite is absent to very rare in samples 37P to 40P, rare in samples 41P to 44P and minor in samples 45P and 46P. In sample 45P botryoidal/framboidal pyrite was observed.

3.1.1c Quartz

Three types of quartz were identified: vitreous glassy quartz; milky/saccharoidal quartz and mineralized quartz. Vitreous and milky quartz are present in minor amounts in all samples and in major amounts in sample 44P. Mineralised quartz is very rare to absent in samples 37P to 40P, 47F, 48F and sample 44P.

3.1.1d Oxides

Oxides are present in all samples in varying amounts. In samples 37P to 39P the amount of oxides is greater than the amount of sulphides, in sample 40P oxides and sulphides are present in approximately equal amounts, and in samples 41P to 46P sulphides are of greater abundance than oxides.

3.1.1e Rocks fragments

Rock fragments are a major component of samples 39P and 40P and are present in minor to trace amounts in all other samples. The rock fragments mainly comprise of mica schist.

3.1.2 Minor mineralogy

3.1.2a Tourmaline

Tourmaline was identified in samples 40P, 41P, 44P and 46P.

3.1.2b Green silicate

An unidentified green vitreous silicate was observed in all samples.

3.1.2c Gold

No appreciable gold (> 3 colours per sample) was observed during the initial panning process or during the microscopic examination of the samples. However, a single small 50 µm rounded grain tentatively identified as gold was observed in sample 41P, three similar grains were also observed in sample 43P.

4. Conclusions

Gold is rare to absent in the concentrates and was only identified optically (and is too small to prove by 'probing'). However, trace amounts of gold were observed (independently) in polished sections 41P and 43P, associated with arsenopyrite; and in pan concentrates where gold colours/grains (up to 50 μm) were also seen.

With so little gold present (if at all) it is difficult to speculate upon its origin. Assuming gold be present, then there is a loose correlation between the presence of gold and arsenopyrite, discrete grains of base metal sulphides (chalcopyrite, sphalerite and galena) and mineralized quartz fragments, namely in samples 40P-43P. There appears to be no correlation between gold and the abundance of skarn garnets. Indeed, the very garnet-rich samples 37-39P have no gold reported in them.

The genesis may well be that of a complex skarn-gold association, with initial skarn silicates followed by quartz-arsenopyrite-base metals-minor gold. If so samples with low numbers (37-42) and high numbers 44, 45, 47 and 48 are away from the source area and have lost their easily oxidized sulphides (or are above the mineralization).

Alternatively, the gold belongs to a quartz-arsenopyrite-pyrrhotite $\pm$ base metal association, many of which are unrelated to skarns.

Table 1. Opaque species in 37P to 46P plus 47 and 48 F

Minerals	37P	38P	39P	40P	41P	42P	43P	44P	45P	46P	47F	48F
Pyrite	Major	Major	Major	Major	Major	Major	Major	Major	Major	Major	Minor	v. minor
Pyrrhotite	Minor	Minor	Minor	Minor	Minor	Minor	Minor	in pyrite	in pyrite	Minor	in pyrite	in pyrite
Marcasite	–	NPM	NPM. Mosaic	after po	after po	NPM	NPM. Mosaic	after po	NPM after po	NPM. Mosaic	–	–
Chalcopyrite	in pyrite	Minor	Minor	Minor	Minor	Minor	Minor	Minor	in pyrite	Minor	in pyrite	in pyrite
CuS, CuFeS	trace covellite	–	trace covellite, cubanite, bornite	trace cubanite	trace cubanite	trace ‘idaite’	trace bornite, covellite	–	–	trace cubanite	trace bornite	–
Sphalerite	–	in pyrite	trace + cp blebs	in pyrite	in pyrite	in pyrite	in pyrite	in pyrite	trace + cp blebs	trace + cp blebs	–	trace + cp blebs
Galena	–	–	in pyrite	in pyrite	v. minor	v. minor	v. minor	in pyrite	in pyrite	trace	–	–
Arsenopyrite	–	v. minor	v. minor	v. minor	v. minor	v. minor	v. minor	–	–	v. minor	–	–
Molybdenite	–	–	–	in pyrite	–	in pyrite	v. minor	–	–	in pyrite	–	–
CuSe?	–	–	–	–	–	–	trace	–	–	–	–	–
Other	–	–	trace pentlandite, millerite	trace pentlandite, millerite	–	trace tetrahedrite in pyrite	trace pentlandite	–	–	–	–	–
Magnetite	Major	Major	Major	Major	Major	Major	Major	Major	Major	Major	Major	Major
Ilmenite	Major	Major	Major	Major	Major	Major	Minor	trace	Major	Major	Major	Major
Hematite	Major	Major	Major	Major	Major	Major	Major	Major	Major	Major	Major	Major
TiO₂ minerals	Minor	rare big rutile?	rare big rutile?	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Sphene	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor	trace	trace
Limonite	Major	Major	Major	Major	Major	Major	Major	Major	Major	Major	Major	Major
Graphite	Minor	trace	–	trace	trace	Minor	trace	–	Minor	Minor	–	–
Chromite	–	–	–	–	–	–	–	–	–	–	trace	trace
Garnets	Snowball	Snowball, unzoned	Snowball, zoned	Snowball, zoned	Snowball, zoned, unzoned	Snowball, unzoned	Snowball, zoned, unzoned	Snowball zoned, unzoned	v. little garnet	Snowball, zoned, unzoned	v. little garnet	v. little garnet
Cassiterite	trace?	–	–	trace?	–	–	–	–	–	–	–	–
White metal	1-5 µm resine	10 µm resine	2-5µm resine	1-10 µm resine	2-5 µm resine	20 µm resine	2-10 µm resine	5 µm resine	10 µm resine	1-5 µm resine	1 µm resine	2 µm resine
Bismuth?	–	–	–	2-5 µm Bi, BiS ₂ in pyrite	–	2-5 µm Bi in pyrite	–	4 µm in pyrite	–	2 µm in pyrite	–	–
Gold (electrum)	–	–	–	–	1 µm in apy	< 1 µm in pyrite?	6 µm - apy	–	–	–	–	–
Yellow metal/ gold	1-10 µm silicate	1-10 µm resine	1-5 µm silicate	1-2 µm silicate	en silicate	1-4 µm silicate	5 µm silicate	10 µm resine	6 µm silicate	4 µm resine	1-5 µm resine/silicate	2 µm resine

Relative proportions are very approximate.

“–” phase not seen. Zoned garnet may be underreported, and cassiterite (if present).

Table 2. Opaque species in 37F to 46F (only at x16 oil)

Minerals	37F	38F	39F	40F	41F	42F	43F	44F	45F	46F
Pyrite	Major	Major	Major	Major	Major	Major	Major	3 grains	Major	Major
Pyrrhotite	Minor	Minor	Minor	Minor	Minor	Minor	Minor	1 grain	in pyrite	Minor
Marcasite	Mosaic	after po	Mosaic	NPM. Mosaic	after po	after po	NPM. Mosaic	–	after po	–
Chalcopyrite	in magnetite	trace	Minor	Minor	Minor	Minor	Minor	trace	Minor	trace in silicate
CuS, CuFeS, etc	–	trace pentlandite, millerite	–	–	–	trace covellite	–	trace bornite	–	trace bornite
Sphalerite	–	trace in silicate	trace	–	trace + cp blebs	–	–	–	trace	trace + cp blebs
Galena	–	–	–	–	–	v. minor	–	–	in pyrite	–
Arsenopyrite	–	–	–	v. minor	–	–	v. minor	–	–	–
Molybdenite	–	–	–	–	–	–	–	–	–	–
Magnetite	Major	Major	Major	Major	Major	Major	Major	Major	Major	Major
Ilmenite	Major	Major	Major	Major	Major	Major	Major	Major	Major	Major
Hematite	Major	Major	Major	Major	Major	Major	Major	Major	Major	Major
TiO₂ minerals	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Sphene	?	Minor	?	Minor	?	Minor	Minor	Minor	Minor	–
Limonite	Major	Major	Major	Major	Major	Major	Major	Major	Major	Major
Graphite	Minor	Minor	Minor	Minor	Minor	–	Minor	–	Minor	Minor
Chromite	–	–	–	–	–	–	–	–	–	–
Garnets	Not done			Not done		Not done				
Cassiterite	trace?	–	–	–	–	–	–	–	–	–
White metal	10 µm resine	6 µm resine	–	–	2-10 µm resine	–	5 µm resine	–	5µm resine	–
Yellow metal/gold	–	–	in silicate	–	10 µm resine	–	–	2-5 µm resine	–	–

Table 3. Silicate phases (coarse panned concentrates) 37P-46P plus 47 and 48F

Minerals	37P	38P	39P	40P	41P	42P	43P	44P	45P	46P	47F	48F
Red garnet	v. rare	v. rare	Rare	v. rare	Rare	v. rare	Rare	v. rare	–	Rare		
Orange garnet	Abundant	Abundant	Abundant	Abundant	Major/Minor	Abundant	Abundant/major	Minor	–	Major-Minor		
Garnet/sulphide	garnet > sulphide	garnet > sulphide	garnet > sulphide	garnet > sulphide	sulphide > garnet	garnet > sulphide	garnet > sulphide	v. little garnet	v. little garnet	sulphide > garnet	v. little garnet	v. little garnet
Milky quartz	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Major	Minor	Minor	Minor	Minor
Vitreous quartz	Minor	Minor	Minor	Minor	Minor	Minor	Minor	?	Minor	Minor	Minor	Minor
Mineralized quartz	v. rare	v. rare	v. rare	v. rare-rare	Rare	v. rare-rare	Rare	Not seen	v. rare-rare	v. rare	Not seen	Not seen
Others	–	–	–	Rare schist	–	–	–	Rock fragments	Metasiltstone, Metashales, Carbonate, Carbonate sediments	Carbonate rocks, Mineralized gastropod	–	–

APPENDIX 5

Petrology of Rocks from the Rio Mulatos Area, Ecuador

by

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October 1987

Sponsored by B.P. Minerals International

1. Summary

This report deals with the petrology of 31 rocks from the Rio Mulatos area which were collected by Martin Litherland of BGS. The suite includes a variety of igneous, metamorphic and metasomatic rocks.

The igneous rocks are dioritic in composition and probably come from high level plutons. They are undeformed and affected by tremolite-epidote-sphene-chlorite alteration.

Most of the other rocks show evidence of regional metamorphism and deformation under upper greenschist to amphibolite facies conditions. These metamorphic rocks include marbles, calc-silicate schists, metapelites, semipelites and amphibolites. Both the carbonates and pelites are locally graphitic. These are interpreted as being the metamorphic products of a mixed carbonate-clastic sedimentary sequence and basic igneous volcanics or intrusions.

The metamorphic rocks show varying degrees of Ca-Fe metasomatism and have been to greater or lesser degrees replaced by epidote and Ca-garnet. This alteration post-dates the regional metamorphic fabric. Rocks composed entirely of variable mixtures of epidote, clinopyroxene, amphibole, Ca-garnet, quartz, magnetite and carbonate typically have no preserved evidence of the regional metamorphism. These are believed to be extreme products of the Ca-metasomatism (skarns). Monomineralic diopside, epidote and clinozoisite skarns also occur in the suite.

Some rocks contain post-kinematic biotite or phlogopite porphyroblasts which may reflect a form of K-metasomatism. One rock is a tourmalinite and is thus a product of extreme B-metasomatism.

The igneous, metamorphic and metasomatic rocks are all affected by veinlet silicification and in one specimen this is associated with adularia (cf. Nambija gold deposits). This silicification post-dates the Ca metasomatism.

The character of the alteration, skarns and composition of the igneous rocks in the suite, all suggest that it is an example of a calcic magnetite skarn of the sort which is a widespread association of high level dioritic intrusions in island arc complexes. Although the suite as a whole is lacking evidence for more evolved acidic intrusive activity and potassic alteration as characterise the Nambija gold deposits, there are some encouraging indications that such features may be present in the Rio Mulatos district.

2. List of specimens with identifications from thin section

261	Serpentine
265†	Pyritic and epidotic muscovite schist
266*†	Epidotized calc-schist
267A*†	Altered (Ca-garnet-epidote-pyrrhotite-amphibole) amphibolite
267H†	Clinozoisite “skarn”
268B†	Impure marble
269B†	Tourmalinite
271B†	Garnet-muscovite schist in contact with amphibolite. Both with epidote-chlorite alteration and garnet alteration in the amphibolite
273†	Biotite (potassic alteration?)-epidote amphibolite
274†	Diopside “skarn”
280†	Siliceous graphitic marble
281†	Epidote-amphibole “skarn”
285A*†	Grossularite-clinopyroxene-amphibole-epidote “skarn”
285B	Altered (epidote-Ca garnet-quartz) amphibolite
285C†	Quartz-grossularite rock
286A†	Altered (epidote-quartz) amphibolite
286B	Altered (epidote) amphibolite with later quartz-adularia-apatite veinlets
286C	Clinopyroxene-epidote-amphibole rock
286D†	Clinopyroxene-amphibole-epidote rock
286E	Clinopyroxene-amphibole-epidote rock
286G*†	Altered (epidote-Ca garnet-magnetite) amphibolite
287	Clinopyroxene-garnet-amphibole “skarn”
288A*	Impure siliceous marble
288B	Quartz-garnet-biotite schist with metamorphic calcite veins.
289†	Graphitic garnet-biotite schist with quartz-calcite veins and grossularite alteration
290B†	Altered (tremolite-epidote-sphene-chlorite) diorite
291A	Altered (calcite-biotite(?)-quartz) plagioclase rock
292A	Clinopyroxene-epidote-magnetite “skarn”
292B†	Epidote “skarn”
293	Quartz-muscovite-albite schist
294	Altered (epidote-tremolite-sphene) porphyritic microdiorite

* Detailed description available; †Microphotography available

3. Summary descriptions by specimen number

- **261 — Serpentine**

Fine-grained serpentine with some highly altered orthopyroxene relicts.

Petrogenesis: An altered ultramafic rock

- **265 — Pyritic and epidotic muscovite schist**

Muscovite (coarse plates and sericite) > epidote $\approx$ opaques ($\approx$ 25%) > quartz > phlogopite, minor sphene, plagioclase and tourmaline (all $\approx$ 1%).

Essentially a quartz-sericite-pyrite schist with the crude layering being defined by variations in the relative proportions of these minerals. A pale green amphibole (tremolitic?) and phlogopite both occur as post-kinematic porphyroblasts. At least a large proportion of the epidote is part of a later vein paragenesis with quartz which is discordant to the layering. This in turn is cut by later quartz veinlets. Tourmaline is quite abundant and occurs as greenish clots scattered about the rock.

Petrogenesis: Probably a regionally metamorphosed pelitic sediment. The unusually fine-grained nature of the mica suggests that this may be a mylonite/phyllonite. If so the phlogopite and amphibole post-date both a regional metamorphic event, and later ductile deformation. Epidote-quartz alteration (Ca-metasomatism is superimposed on all these features). The abundant pyrite predates the vein epidote but need not be sedimentary as it could have been introduced during a mylonite-forming event.

- **266 — Epidotized calc-schist (more detailed description also provided below)**

Quartz >> epidote > actinolite (possibly hornblende) > orange-pink garnet > chlorite with minor pyrite and (?) sphalerite.

A quartz-garnet-actinolite schist which has been partially replaced by epidote and lesser secondary quartz. Quartz grain shape/preferred orientation of chlorite and actinolite define a schistosity which is “wrapped around” the garnet showing that the latter are pre- or syntectonic (i.e. not part of the alteration assemblage). Some fine-grained epidote could be primary.

Alteration consists of irregular semiconcordant epidote aggregates and quartz veinlets. Epidote commonly contains altered relict amphibole and is strongly zoned, including reddish brown material which is probably the Mn-bearing variety (piemontite). Sulphides are disseminated and also occur in selvages to garnets.

Petrogenesis: A regionally metamorphosed impure calcareous and argillaceous sandstone or chert with epidote-quartz alteration which post-dates the ductile fabric.

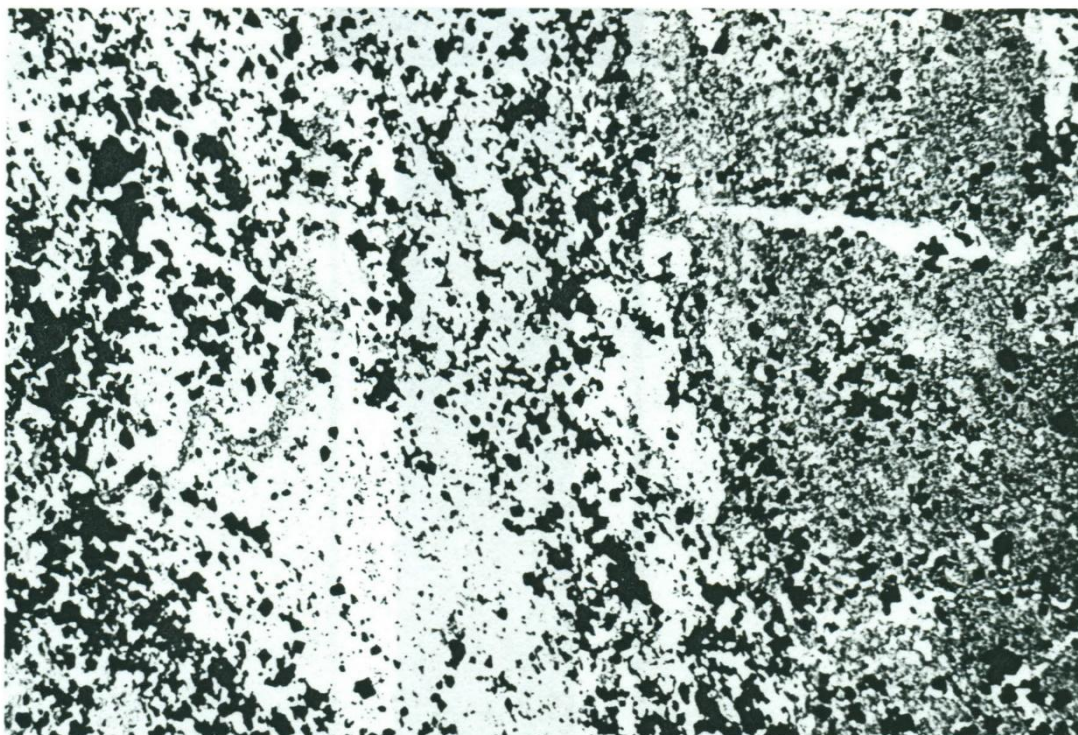


Plate 1A: Pyritic muscovite schist (265) with post tectonic phlogopite porphyroblasts (pale brown) and epidote alteration (high relief) - PPL, field of view 8mm.

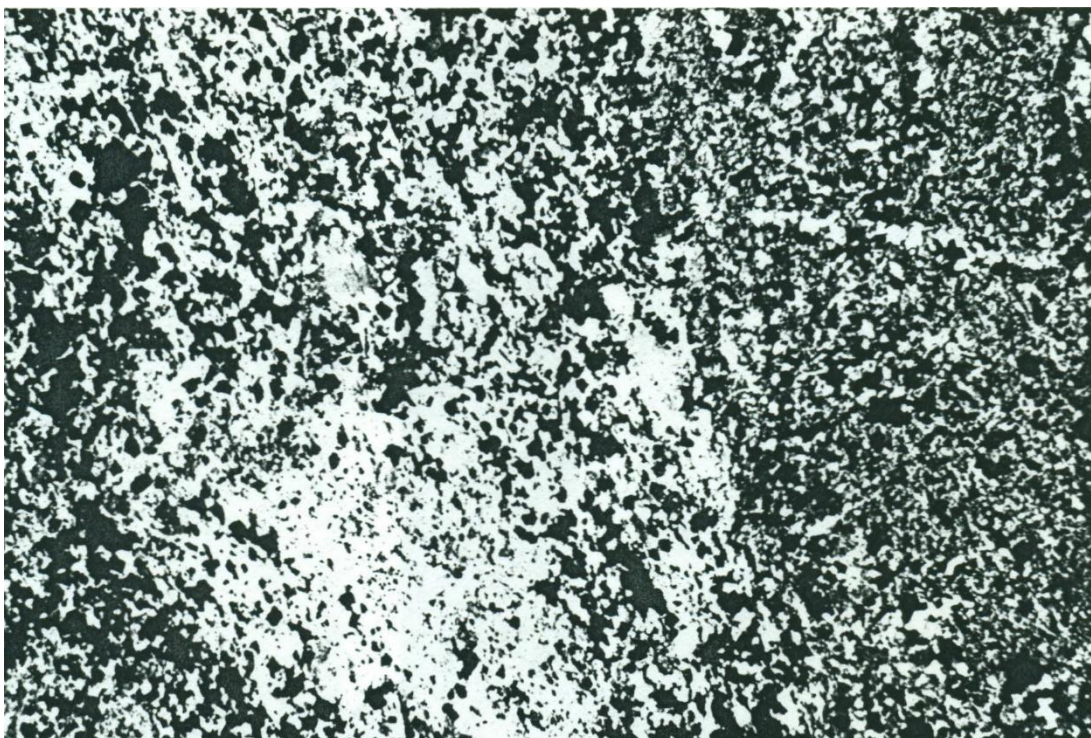


Plate 1B: Same view (265) in XPL.

- **267A — Altered (Ca-garnet-epidote-pyrrhotite-amphibole) amphibolite (more detailed description also provided below)**

Host rock: Green amphibole (hornblende/actinolite) > quartz 1, accessory sphene.

Alteration: Ca-garnet > epidote > pyrrhotite > Fe-rich amphibole > quartz 2 ≈ carbonate > chalcopyrite.

A crudely foliated and layered amphibole-quartz rock which has been partially replaced by a variety of secondary minerals. Anisotropic Ca garnet occurs as porphyroblasts and as later overgrowths and veins with epidote. These veins have been invaded by a sulphide-quartz-carbonate association. Sulphides are concentrated in partially-replaced host rock vein selvages and are associated with a secondary dark coloured and strongly pleochroic amphibole (deduced to be Fe-rich, possibly ferroactinolite).

Petrogenesis: A regionally metamorphosed basic rock which underwent several stages of alteration (predominantly Ca-metasomatism followed by the introduction of sulphides) after the development of the ductile fabric.

- **267H — Clinozoisite “skarn”**

Clinozoisite (≈95%) >> carbonate > garnet >> opaques (≈1%). Minor late limonite veinlets.

Clinozoisite occurs as only very slightly zoned crystals of highly variable grain size and with no preferred orientation. The pink colour of the rock is almost certainly due to this mineral. Systematic grain size variation produces a layering and carbonate and opaques have textural affinities with the coarser layers. The rock does not give a reaction with dilute acid and the carbonate may therefore be a Mg, Mn or Fe-bearing variety. Garnet occurs as bands of equant xenomorphic grains which lie parallel to the grain size layering.

Petrogenesis: The near monomineralic character, composition and texture of this rock suggest that it is metasomatic. The protolith was probably highly aluminous (pelitic?).

- **268B — Impure marble**

Calcite > garnet > chlorite > opaques > quartz.

A granoblastic to schistose rock with inclusion-rich, “net textured” garnet porphyroblasts. Chlorite occurs as coarse plates which define a schistosity and also as random textured pseudomorphous masses suggesting that it is a retrograde phase, probably derived from biotite or phlogopite. The schistosity is “wrapped around” the garnets showing that the latter are pre- or syntectonic. Opaque phases constitute ≈ 10% of the rock - paragenesis unclear. Minor carbonate-chlorite veinlets cut the rock and may be of the same age as the assumed chloritization.

Petrogenesis: A regionally metamorphosed argillaceous limestone.

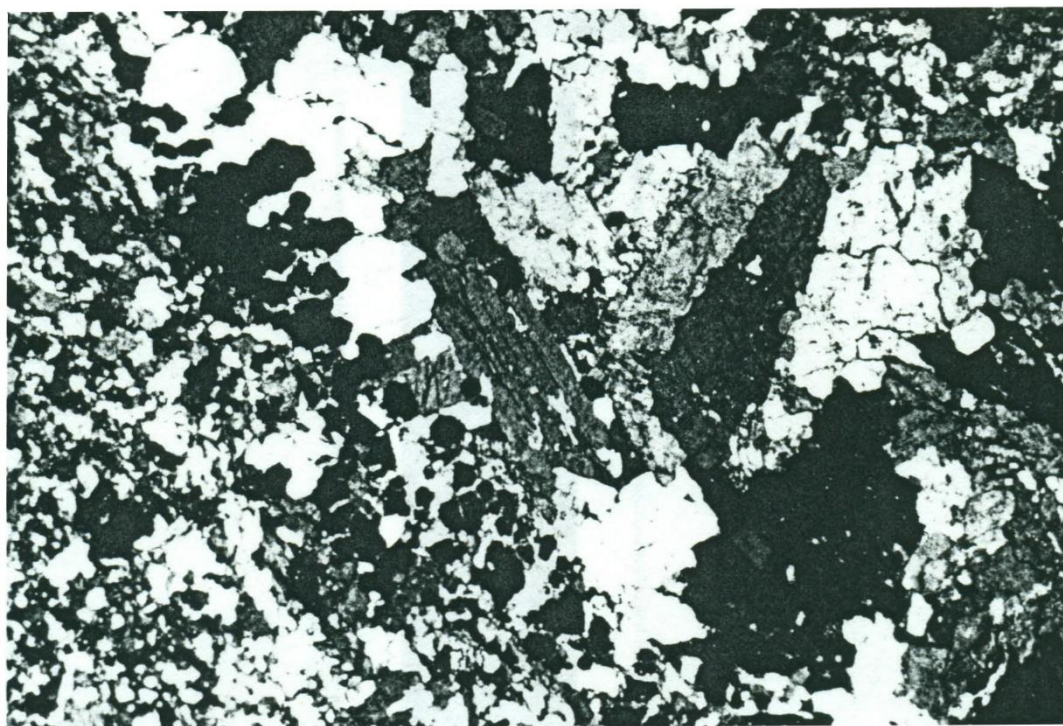


Plate 2: Clinozoisite skarn (267H) with garnet band (top left-middle bottom)- XPL, field of view 3.5mm.

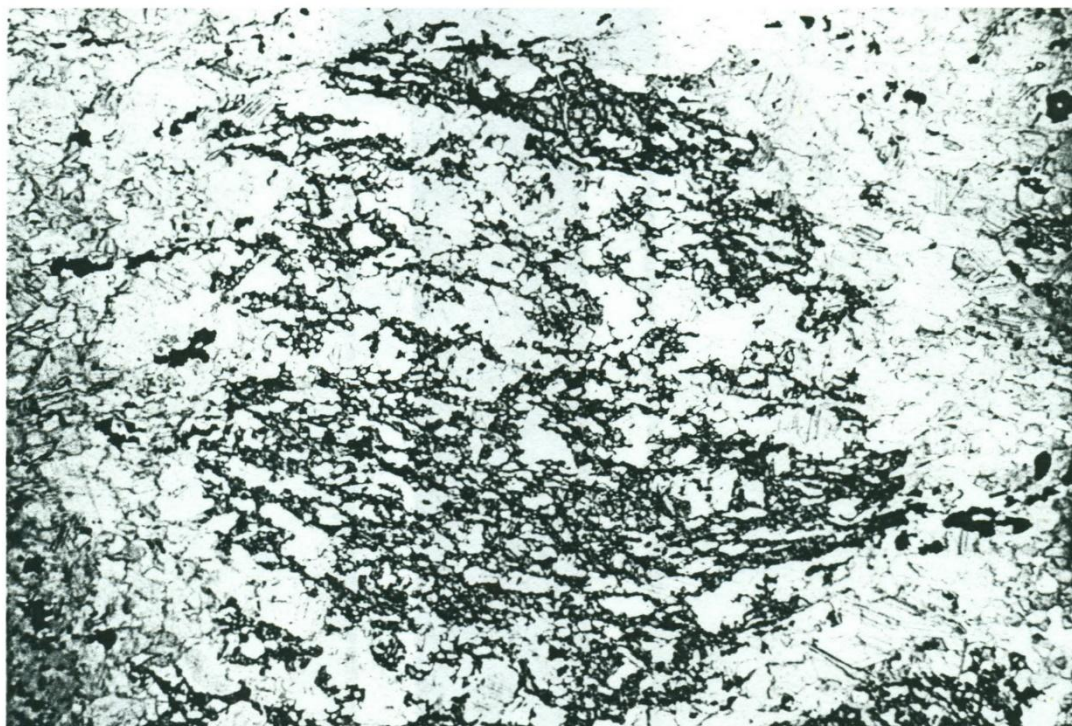


Plate 3A: Sieve or net-textured garnet porphyroblast in siliceous marble (268). PPL field of view 8mm.

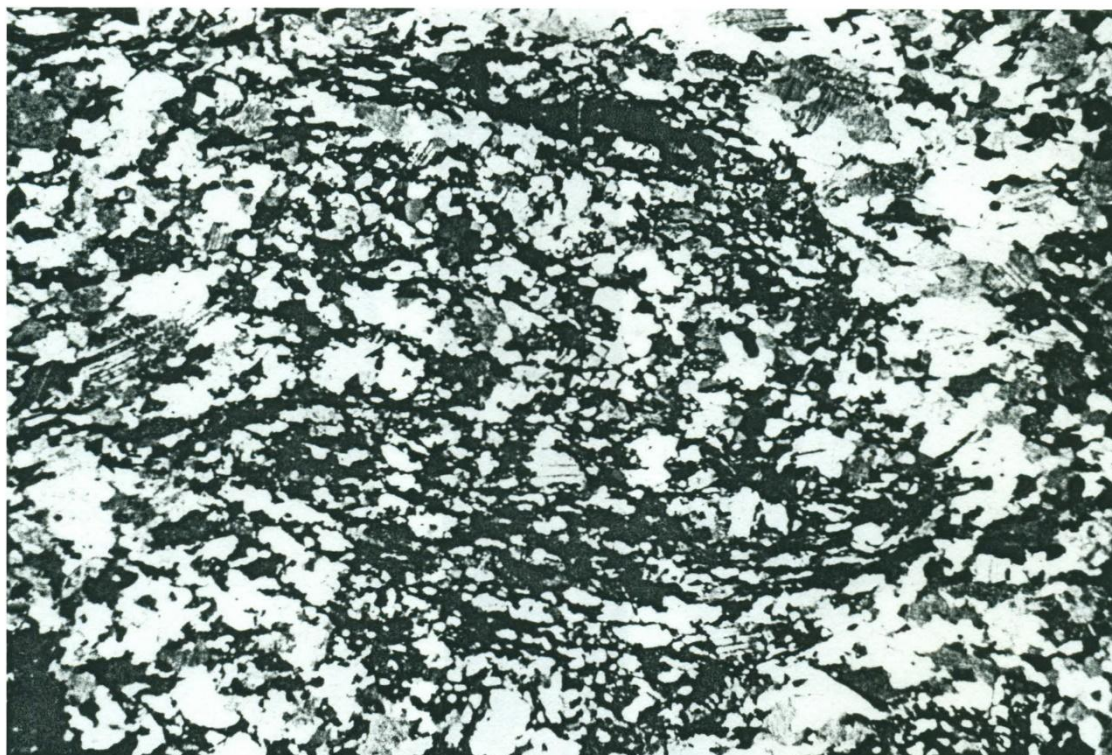


Plate 3B: Same view (268) in XPL.

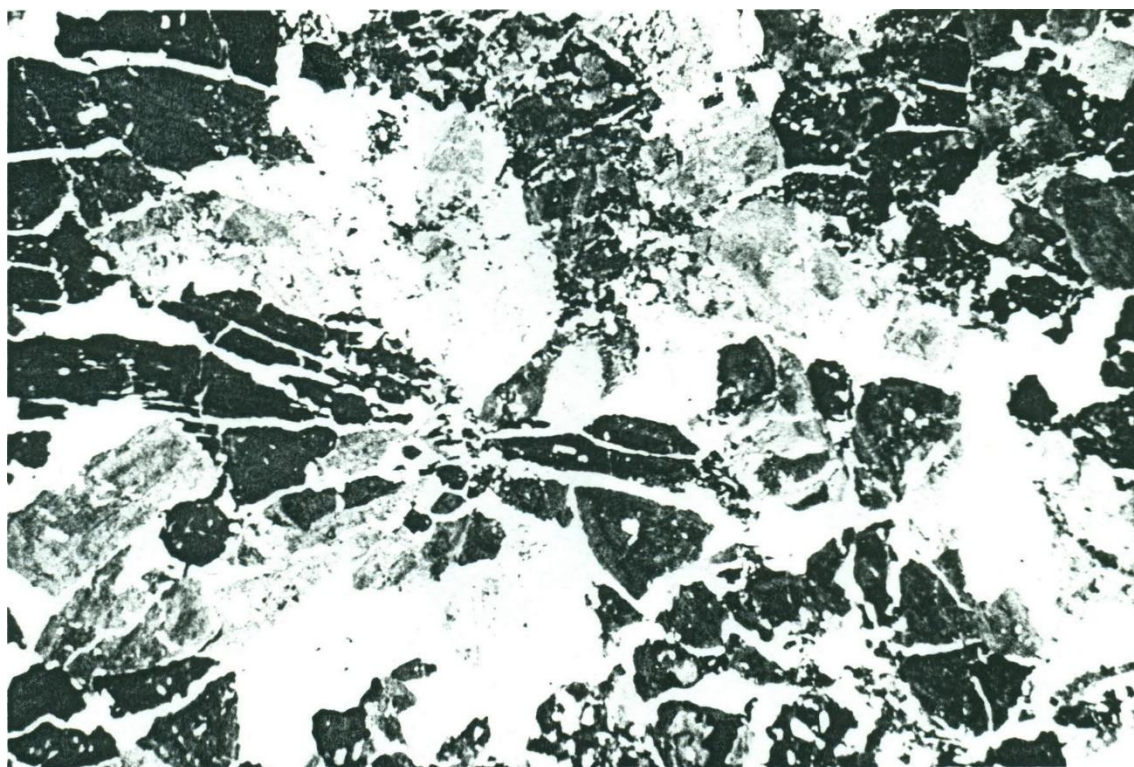


Plate 4: Cataclastic tourmalinite (269B) invaded by quartz veins - PPL, field of view 8mm.

- **269B — Tourmalinite**

Green-brown tourmaline >> quartz with minor muscovite, chlorite, zoisite, chalcopyrite and accessory zircon and rutile.

A random textured coarse tourmaline rock. The tourmaline exhibits strong cyclic zoning (probably variations in the schorl-dravite series). This particularly brittle mineral exhibits a partial cataclastic texture and the fragmented material has been invaded by quartz. Minor opaques seen in thin section belong to the fracture-hosted paragenesis.

Petrogenesis: A metasomatic rock. There is no evidence of the character of the protolith (most tourmalinites are derived from pelites). Random texture suggests B-rich fluids may have been introduced after the regional metamorphism seen in the other rocks

- **271B — Garnet-muscovite schist in contact with amphibolite. Both with epidote-chlorite alteration and garnet alteration in the amphibolite**

Schist fraction: Muscovite > garnet > biotite.

Contact zone: Plagioclase-quartz-green amphibole-opaques.

Amphibolite: Green amphibole (hornblende) >> garnet > biotite > quartz.

A complex rock in which a pelitic schist with synkinematic garnets and “wrapped around” texture passes through a foliated plagioclase-quartz-amphibole rock into an amphibolite with strong preferred orientation of green amphibole prisms (L-fabric) and thin biotite folia. The garnets in the schist have biotite pressure shadows. All of these minerals must have formed during the regional metamorphism. The amphibolite also contains garnets but these have helicitic (post-kinematic) inclusion fabrics and the mineral could be part of a skarn alteration paragenesis in this fraction of the rock. Epidote occurs throughout and particularly in the hand specimen gives the impression of being a patchy post-schistosity replacement feature. Biotite and garnet are both extensively altered to chlorite.

Petrogenesis: Regionally metamorphosed pelitic sediment and basic rock, both of which were affected by epidote-chlorite alteration (Ca-metasomatism, hydration) after the formation of the ductile fabric. Post-kinematic garnet in the amphibolite may be an earlier alteration product.

- **273 — Biotite (potassic alteration?)-epidote amphibolite**

Pale-green amphibole (actinolite?) > quartz (the rock could contain some untwinned plagioclase) ≈ biotite (retrograded to chlorite) > epidote with minor carbonate. Pyrite present in the hand specimen.

A weakly foliated amphibole-quartz rock. With large post-kinematic biotite-porphyroblasts which could be products of K-metasomatism. All these minerals are cut by minor quartz veinlets which locally have some carbonate in them. The status of the epidote is unclear. While it is compatible with the metamorphic assemblage, comparison with other rocks in the suite suggest that it could be secondary.

Petrogenesis: A metamorphosed basic rock with possible potassic alteration.



Plate 5A: Garnetiferous metapelite (right) and transition to epidote altered quartz-plagioclase-amphibole rock (271B) - PPL field of view 8mm.



Plate 5B: Amphibolite (left) with biotite (bottom left) passing through strongly epidotised zone into quartz-plagioclase-amphibole rock (271B) - PPL, field of view 8mm.

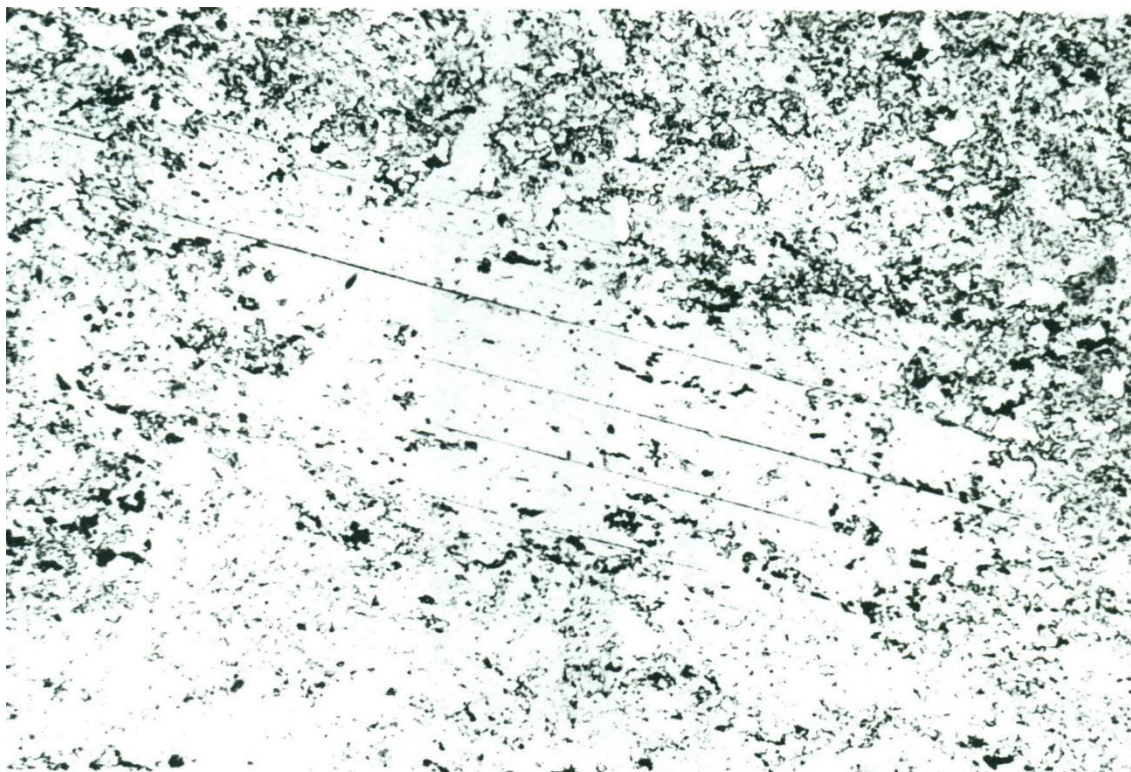


Plate 6: Post kinematic biotite porphyroblast in amphibolite (273) - PPL, field of view, 3.5 mm.

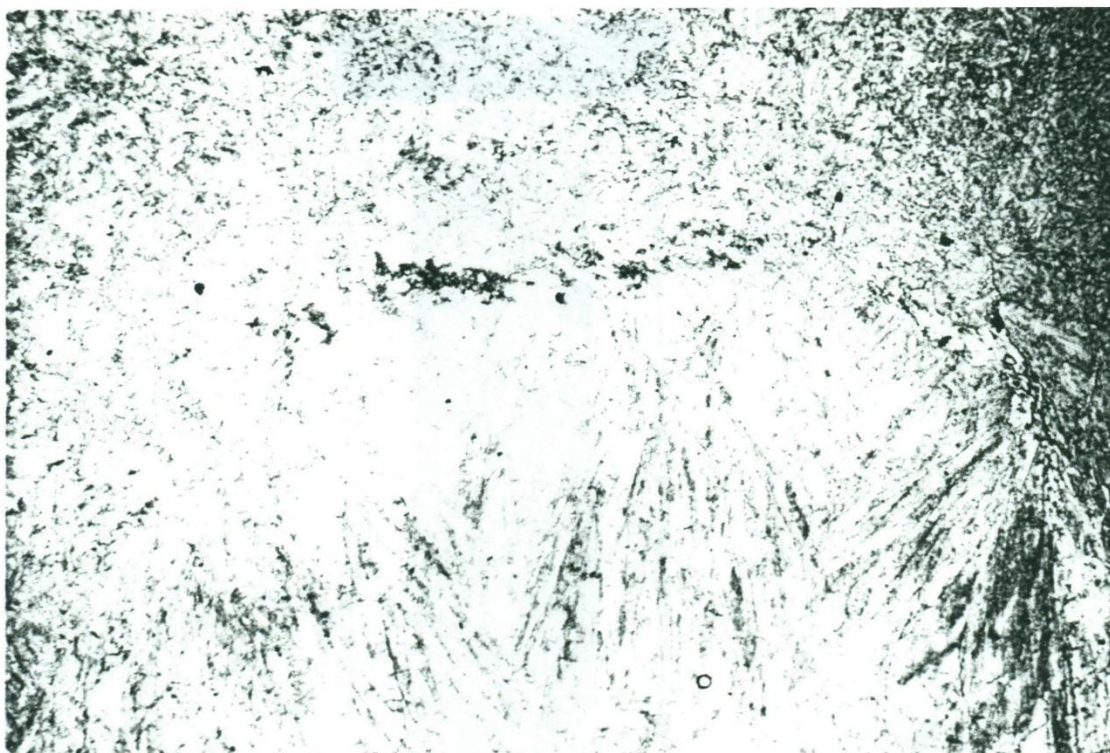


Plate 7A: Diopside skarn (274) with grainsize-variation layering- PPL, field of view 8mm.

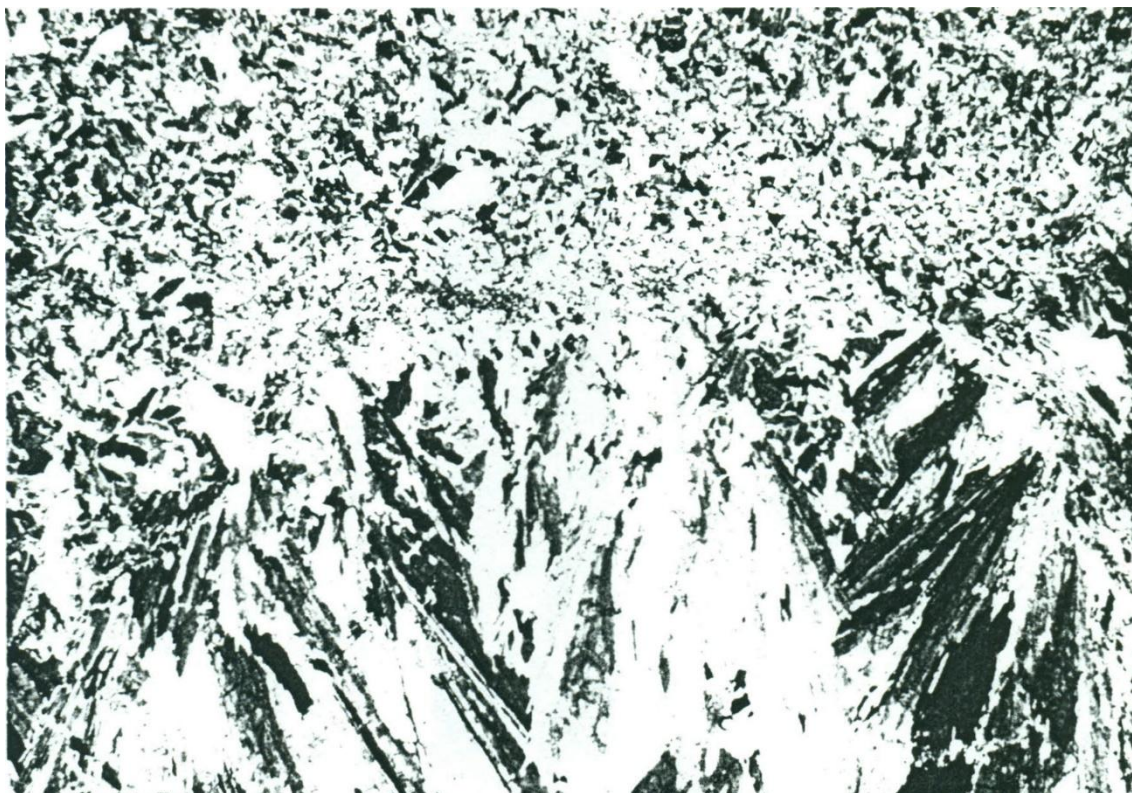


Plate 7B: Same view (274) in XPL

- **274 — Diopside “skarn”**

Clinopyroxene >> tremolitic amphibole $\approx$ calcite (pyrite seen in hand specimen).

The rock is predominantly composed of prismatic clinopyroxene which occurs as radiating bundles of crystals. It is colourless in thin section, pale green in hand specimen and could be mistaken for an amphibole on the basis of its grain morphology. It is probably diopside. Like the clinozoisite skarn (267H) the rock is organised into layers characterised by varying grain size. Small amounts of tremolite and calcite occur as interstitial minerals.

Petrogenesis: The near monomineralic character, composition and texture of this rock suggest that it is metasomatic. Its magnesian character suggests that it was produced from a dolomite or dolomitic limestone.

- **280 — Siliceous graphitic marble**

Calcite >> quartz with minor muscovite or talc (not distinguishable under the microscope), graphite, opaques and a high relief, isotropic brown mineral which may be sphalerite.

Fine-medium grained calcite exhibits a slightly modified granoblastic texture suggesting minor post-crystallization strain. Preferred orientation of phyllosilicates imparts a very weak schistosity. Very fine-grained graphite is concentrated in irregular patches a few mm in size. The rock is crossed by coarse-grained quartz veins with subsidiary carbonate.

Petrogenesis: A regionally metamorphosed, possibly carbonaceous limestone (the paragenesis of the graphite is uncertain).

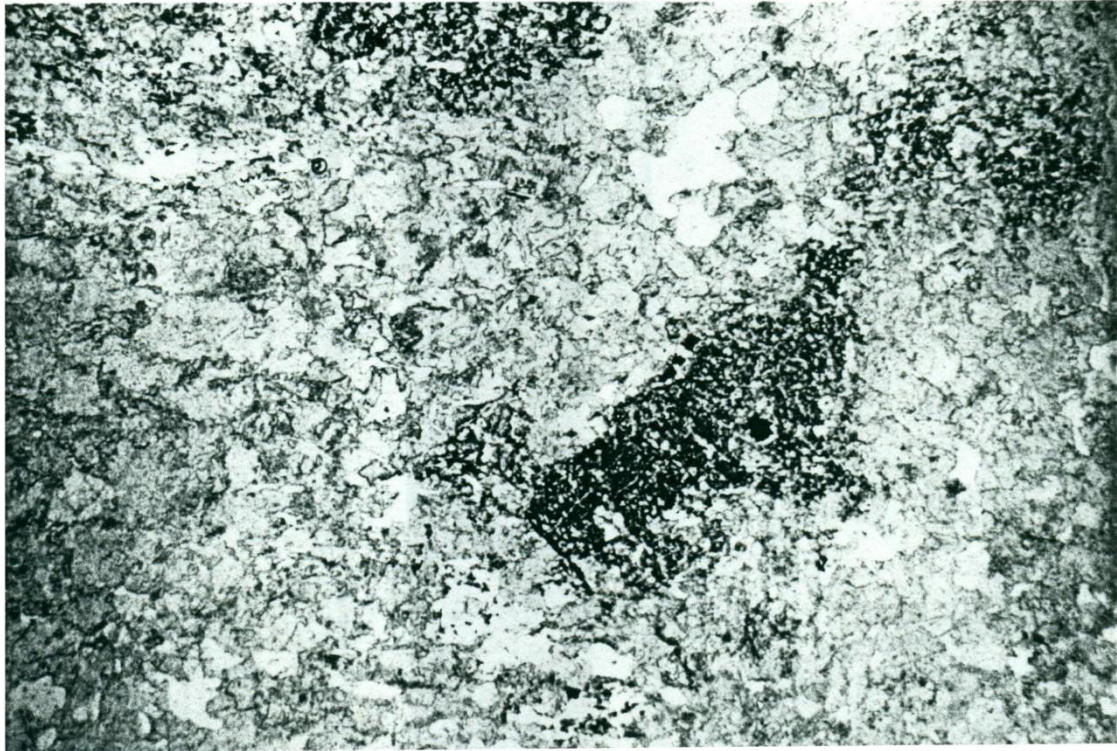


Plate 8: Graphitic patches in siliceous marble (280) - PPL field of view 8mm.

- **281 — Epidote-amphibole “skarn”**

Calcite $\approx$ epidote/clinozoisite $\approx$ green amphibole (actinolite or hornblende) > opaques ($\approx$ 10%, mostly magnetite) with minor quartz and biotite/phlogopite and accessory sphene.

The rock has a domainal texture being separated into strongly zoned epidote-clinozoisite rich domains (pale green in hand specimen) and epidote-amphibole-calcite (dark in hand specimen) domains. The compositional domains are elongate and thus impart a layering to the rock. Magnetite is disseminated throughout and also occurs concentrated in narrow layers with epidote which are highly discordant to the layering. Excepting minor quartz-carbonate veinlets, the paragenetic relationships are not clear, though epidote-magnetite may post-date amphibole-calcite. There are no textural features which can be unequivocally assigned to the regional metamorphic phase.

Petrogenesis: Probably a metasomatic rock - protolith uncertain.

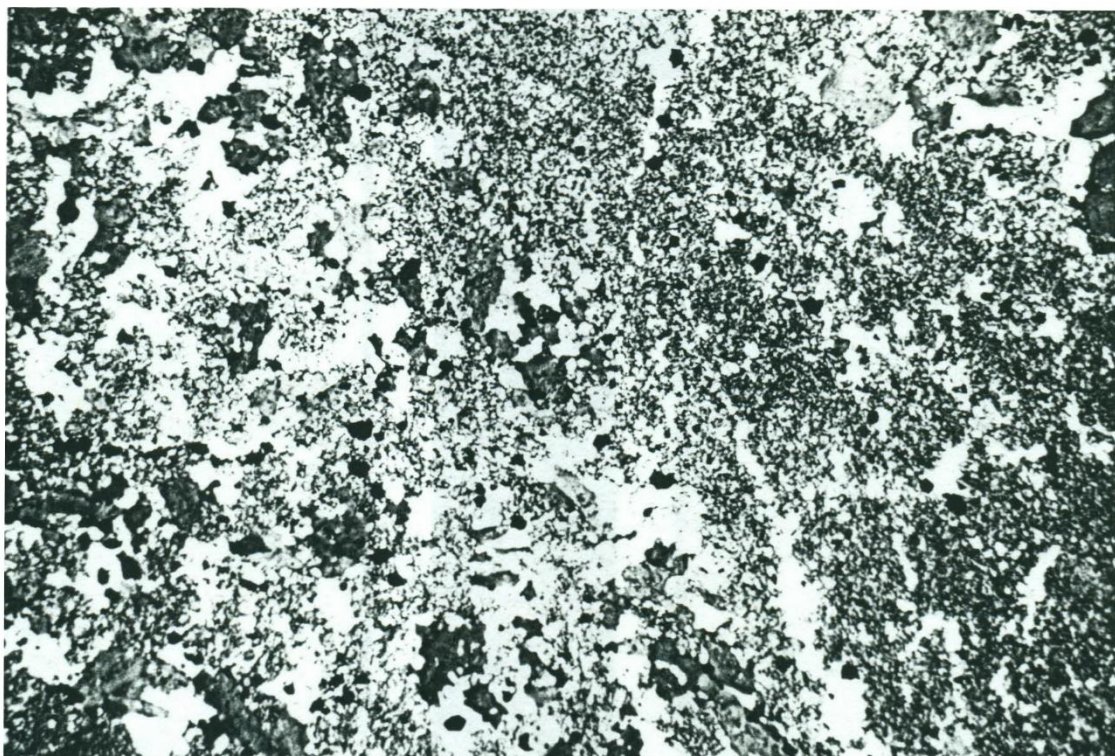


Plate 9A: Domainal texture in epidote (strong relief/yellow green)-amphibole (bluish green)-magnetite skarn (281) - PPL, field of view 8mm.

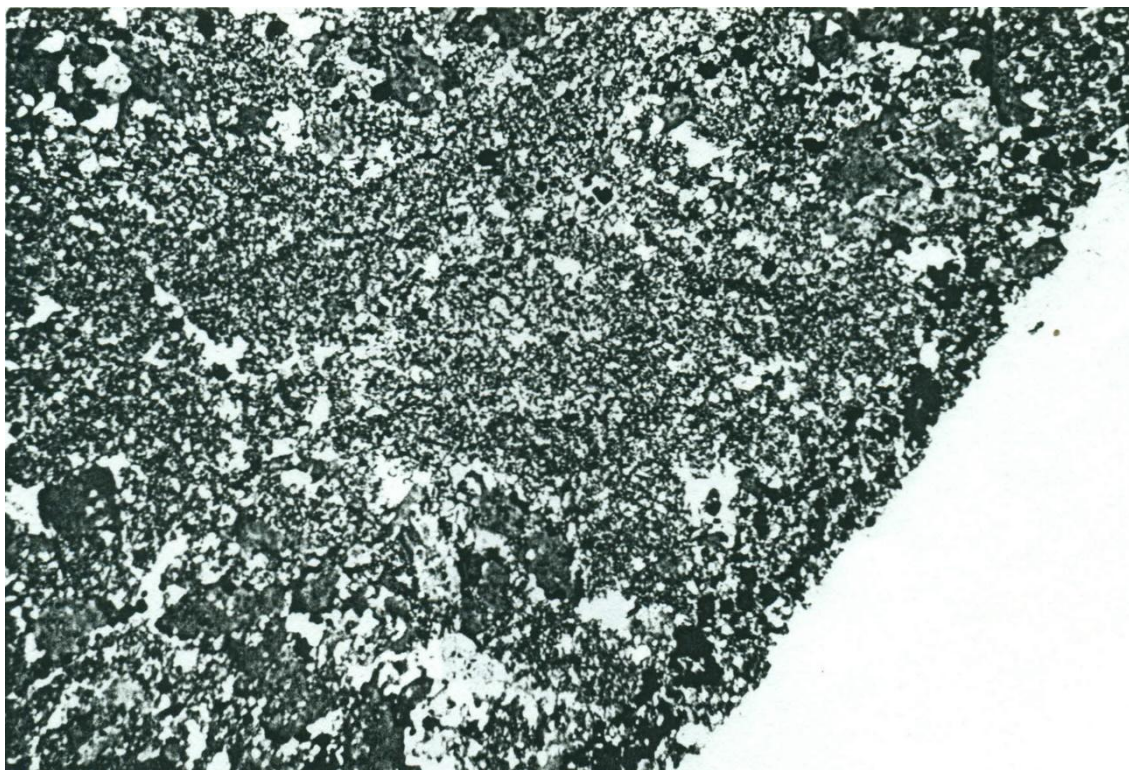


Plate 9B: Magnetite band at edge of section in epidote-amphibole skarn (281) - PPL, field of view, 8mm).

- **285A — Grossularite-clinopyroxene-amphibole-epidote “skarn” (more detailed description also provided below)**

Grossularite > quartz > epidote > calcite $\approx$ green clinopyroxene (probably hedenbergite) > green amphibole (hornblende or actinolite) > opaques ($\approx$ 1%).

Garnet predominates. Its anomalous anisotropy and pinkish white colour in hand specimen suggest that it is grossularite. It occurs as fine-grained aggregates and sieve-textured poikiloblasts. Clinopyroxene is also poikiloblastic. Epidote may be part of a later paragenetic association as some of it occurs in veins with calcite. There are no textural features which can be unequivocally assigned to the regional metamorphic phase.

Petrogenesis: Probably a metasomatic rock - protolith uncertain.

- **285B — Altered (epidote-Ca garnet-quartz) amphibolite**

A fine-grained weakly foliated rock composed of a green amphibole (probably hornblende or tremolitic hornblende) which exhibits heterogeneous replacement by:

Quartz > garnet $\approx$ epidote > green clinopyroxene (probably hedenbergite) > opaques (pyrite $\approx$ 2% in the altered zones) > apatite.

The garnet has anomalous anisotropy (= Ca garnet) and is zoned. Some of the epidote-garnet occur in vein-like replacive structures which cross the foliation and demonstrate the secondary character of these minerals. Epidote-garnet alteration is itself cut by later veins of quartz and pyrite.

Petrogenesis: A regionally metamorphosed basic rock which has undergone Ca-metasomatism, and then silicification with pyrite. Both phases of alteration post-date the ductile fabric.

- **285C — Quartz-grossularite rock**

Quartz > grossularite > clinopyroxene > calcite

A fine-grained quartz-garnet (anomalous anisotropy, white in hand specimen) rock with minor very fine-grained clinopyroxene. Quartz grain shape defines a metamorphic fabric. Some of the garnet is clearly paragenetically late as it occurs with coarse-grained quartz in a vein association which cuts this fabric. Later-still calcite veinlets may be a weathering feature (calcrete).

Petrogenesis: Either a regionally metamorphosed marl with later calc-silicate alteration or a semipelitic metasediment which has undergone post-metamorphic high temperature Ca-metasomatism.

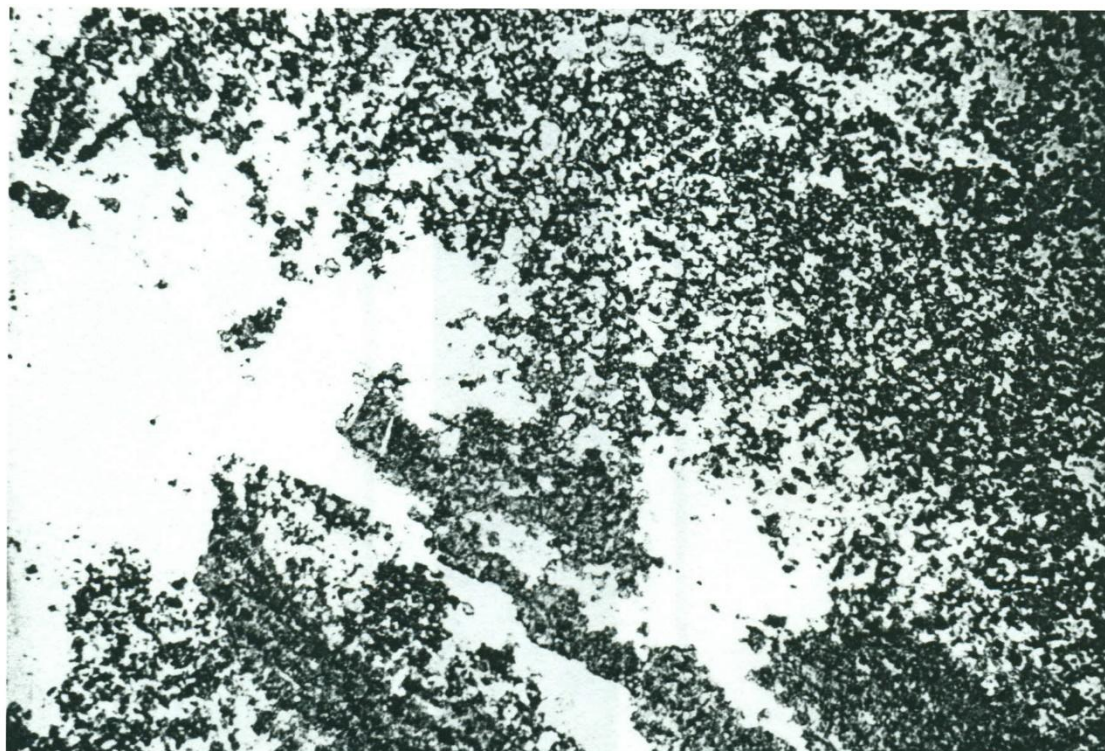


Plate 10A: Quartz-grossularite rock with garnet vein (middle bottom) and late silicification (285C)- PPL, field of view 8mm.

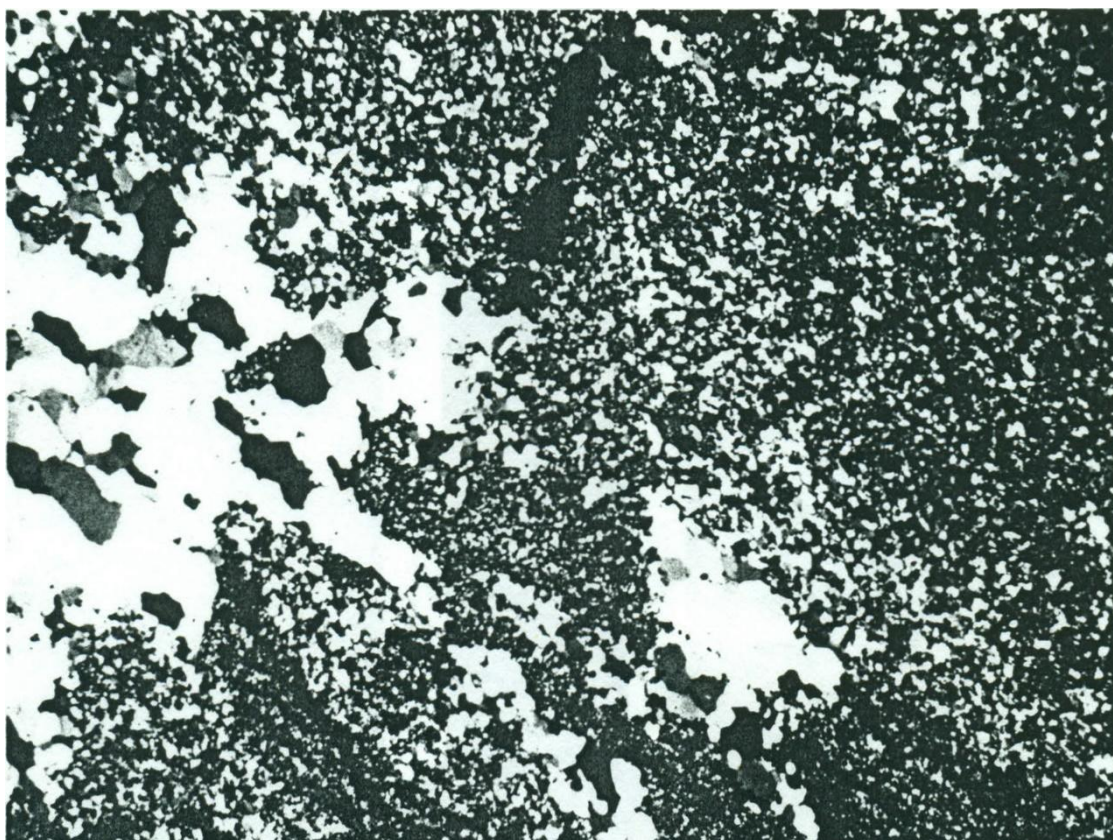


Plate 10B: Same view (285C) in XPL

- **286A — Altered (epidote-quartz) amphibolite**

Green amphibole (hornblende?) $\approx$ epidote $\approx$ quartz > pale amphibole (tremolite?), minor opaques (< 1%).

A weakly foliated fine-grained amphibole-quartz rock. Semipervasive fine-grained epidote alteration is developed in patches (the secondary character of the major epidote development is more obvious in hand specimen - some of the fine-grained epidote in the amphibolite could be a primary metamorphic phase). The rock is transected by an irregular network of relatively coarse-grained quartz-epidote and quartz-pale amphibole veins.

Petrogenesis: A regionally metamorphosed basic rock which underwent Ca-metasomatism after the development of the ductile fabric.

- **286B — Altered (epidote) amphibolite with later quartz-adularia-apatite veinlets**

Quartz > pale green amphibole (actinolite/hornblende) $\approx$ epidote. Opaques < 1%, very minor adularia and apatite.

A well-foliated, fine-grained quartz-amphibole schist. Some of the fine-grained epidote in the amphibolite could be a primary metamorphic phase but much of this mineral occurs as replacive patches (cf. 286A). The epidote patches are themselves cut by irregular quartz veinlets which contain a little adularia and apatite. The opaque phases in the thin section occur in these latter veinlets and are intergrown with the feldspar.

Petrogenesis: A regionally metamorphosed basic rock which underwent two phases of alteration/veining after the development of the ductile fabric.

- **286C — Clinopyroxene-epidote-amphibole rock**

Green clinopyroxene (probably hedenbergite) > pale green amphibole (actinolite/hornblende) > quartz $\approx$ calcite > opaques (pyrite $\approx$ 1%)

Generally similar to 286D & E being a foliated rock with prismatic clinopyroxene ($\approx$ 1 mm) and irregular epidote grains set in fine-grained amphibole. The texture suggests that the epidote could be replacing the clinopyroxene and there is a textural affinity between the epidote and the opaque phases (pyrite) in the thin section. Quartz and calcite occur in a later vein/replacement paragenesis in which the quartz is slightly strained.

Petrogenesis: Problematical – mineralogy consistent with a metasomatic “skarn” but the fabric may be a product of regional metamorphism. It could be a basic rock.

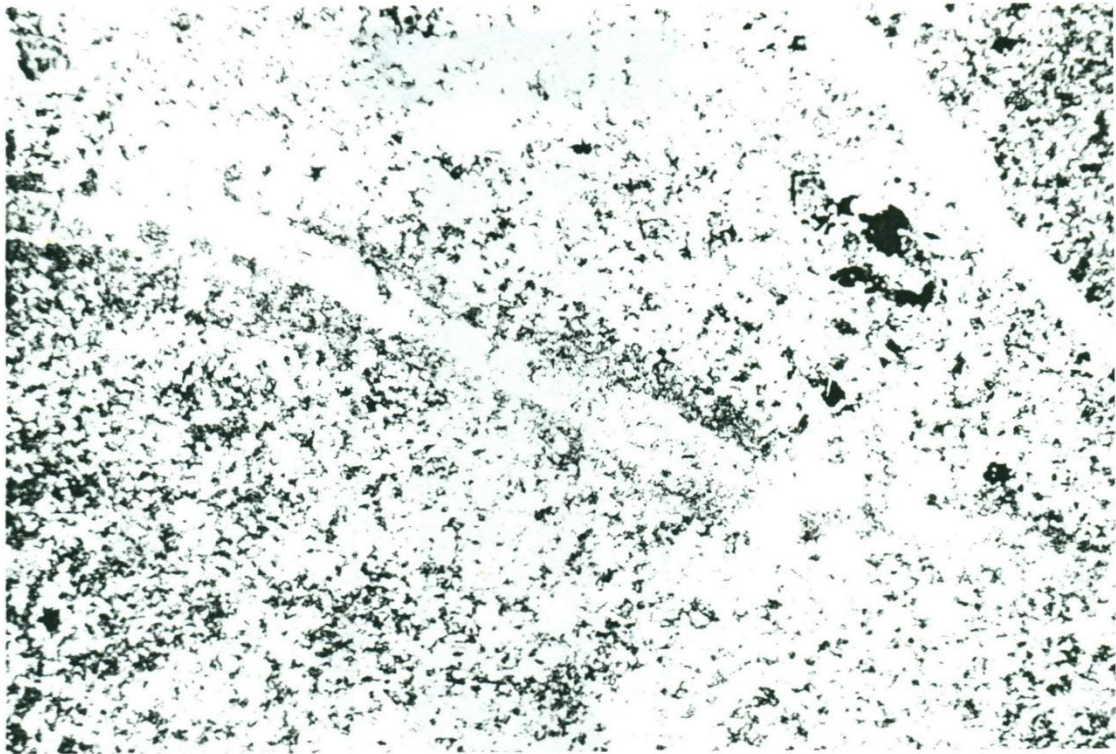


Plate 11A: Epidote-quartz and quartz veinlets in amphibolite (286A) - PPL, field of view 8mm.

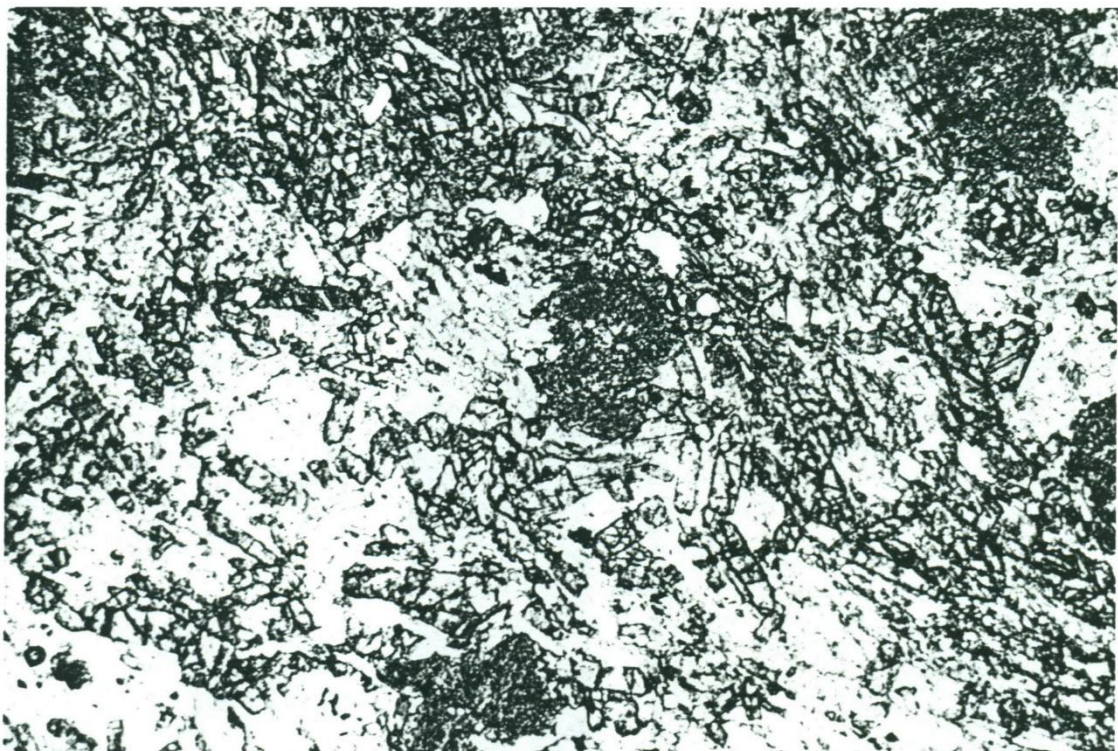


Plate 11B: Epidote (high relief)-clinopyroxene (prismatic)-amphibole rock (286D)- PPL, field of view 8mm.

- **286D — Clinopyroxene-amphibole-epidote rock**

Pale green amphibole (actinolite?) $\approx$ green clinopyroxene (hedenbergite?) $>$ epidote $>$ feldspar $>$ opaques ($\approx$ 1%).

Epidote and prismatic clinopyroxene porphyroblasts ($\approx$ 1-2mm) lie in a fine-grained randomly oriented matrix of pale green amphibole and locally a low relief/birefringence untwinned mineral taken to be feldspar. Clinopyroxene prisms have a preferred orientation which gives the rock an L-S fabric.

Petrogenesis: Problematical - mineralogy consistent with a metasomatic “skarn” but the fabric may be a product of regional metamorphism. It could be a basic rock.

- **286E — Clinopyroxene-amphibole-epidote rock**

Pale green amphibole (actinolite?) $\approx$ green clinopyroxene (hedenbergite?) $>$ epidote $>$ feldspar.

Very similar to 286C/D. Light coloured patches are relatively rich in the low relief/birefringence untwinned mineral taken to be feldspar.

Petrogenesis: See 286C/D.

- **286G — Altered (epidote-Ca garnet-magnetite) amphibolite (more detailed description also provided below)**

Green amphibole (hornblende/actinolite) $>$ epidote $>$ magnetite $\approx$ Ca garnet $>$ quartz, traces of pyrite, chalcopyrite and carbonate.

A medium-grained amphibole schist which has been partially replaced by semi-concordant to discordant Ca-silicate minerals and disseminated magnetite. The garnet exhibits anomalous anisotropy consistent with it being a calcic variety.

Petrogenesis: A regionally-metamorphosed basic rock which underwent Ca-metasomatism and magnetite mineralization after the development of the ductile fabric.

- **287 — Clinopyroxene-garnet-amphibole “skarn”**

Green clinopyroxene (probably hedenbergite) $>$ calcic garnet $\approx$ green amphibole (actinolite or hornblende) $\approx$ epidote $>$ quartz.

A domainal-texture rock with 1) massive medium-grained clinopyroxene-subidiary amphibole domains, 2) poikilitic garnet with clinopyroxene inclusions domains and 3) fine-grained epidote domains. A second type of garnet occurs as minute salmon pink crystals in some clinopyroxene domains associated with quartz-rich patches. There are no textural features which can be unequivocally assigned to the regional metamorphic phase.

Petrogenesis: Probably a metasomatic rock - protolith uncertain.

- **288A — Impure siliceous marble (more detailed description also provided below)**

Calcite > quartz > garnet > tremolite > opaques (including some graphite $\approx$ 3%) >> biotite and retrograde chlorite.

A compositionally layered marble with a schistosity defined by quartz grain shape and the orientation of phyllosilicates and tremolite. The garnets have synkinematic inclusion trails. All these minerals must be products of regional metamorphism. Opaque phases are intergrown with these metamorphic minerals and may be primary or (regional) metamorphic. Chlorite is a retrograde product of both garnet and biotite. There are patches and veinlets of relatively coarse-grained and unstrained post-metamorphic quartz.

Petrogenesis: A regionally metamorphosed siliceous limestone with dolomitic, argillaceous and carbonaceous impurities.

- **288B — Quartz-garnet-biotite schist with metamorphic calcite veins**

Quartz > garnet > biotite/retrograde chlorite >> muscovite. Approximately 10% of the specimen consists of calcite veins.

Quartz and phyllosilicates define a good schistosity. The garnets have synkinematic inclusion fabrics and are wrapped around by the fabric. All of these minerals belong to the regional metamorphic event. A network of large concordant but locally discordant calcite veins is developed. The concordant veins are boudinaged which demonstrates that they belong to the regional metamorphic phase and are therefore not part of a superimposed skarn alteration. The boudins are asymmetric consistent with their having developed under conditions involving simple shear.

Petrogenesis: A regionally metamorphosed pelitic sediment with metamorphic calcite veins.

- **289 — Graphitic garnet-biotite schist with quartz-calcite veins and grossularite alteration**

Rock: Quartz > garnet (almandine) $\approx$ biotite (in part altered to chlorite) > graphite.

Veins and altered host rock fragments: Quartz > calcite > garnet (grossularite), minor rutile, graphite and secondary clinozoisite.

A richly graphitic biotite schist with abundant $\approx$ 0.1 mm xenomorphic, mostly unaltered garnets. These are reddish in hand specimen and probably almandine-rich. The schistosity is “wrapped around” these garnets showing them to be products of regional metamorphism. The rock has been invaded by quartz veins which have filled brittle fractures and detached fragments of the host rock. The host rock fragments are largely composed of a second form of garnet (deduced to be grossularite) which is off white in hand specimen and which occurs as large aggregates of subidiomorphic grains showing extensive alteration to carbonate and clinozoisite.

Petrogenesis: A regionally metamorphosed carbonaceous pelitic sediment which underwent Ca-metasomatism during a late brittle fracturing event.

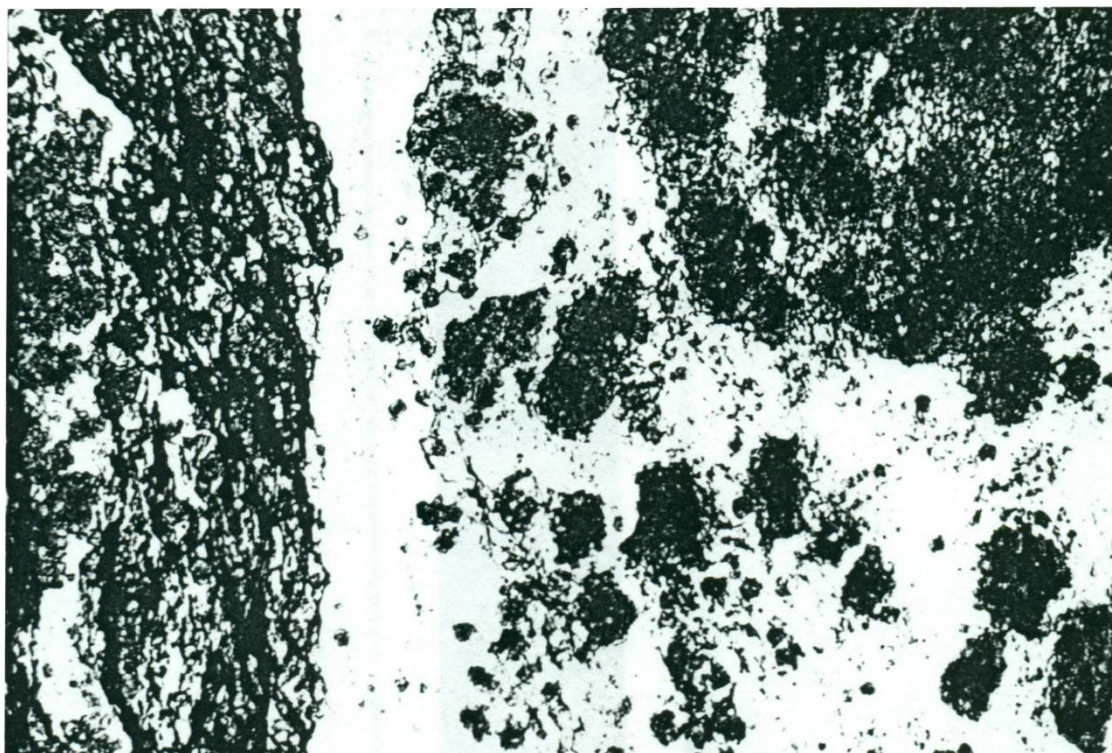


Plate 12A: Graphitic garnet schist (left) with calcite-quartz vein and included wall rock fragments altered to Ca-garnet (289) - PPL, field of view 8mm.

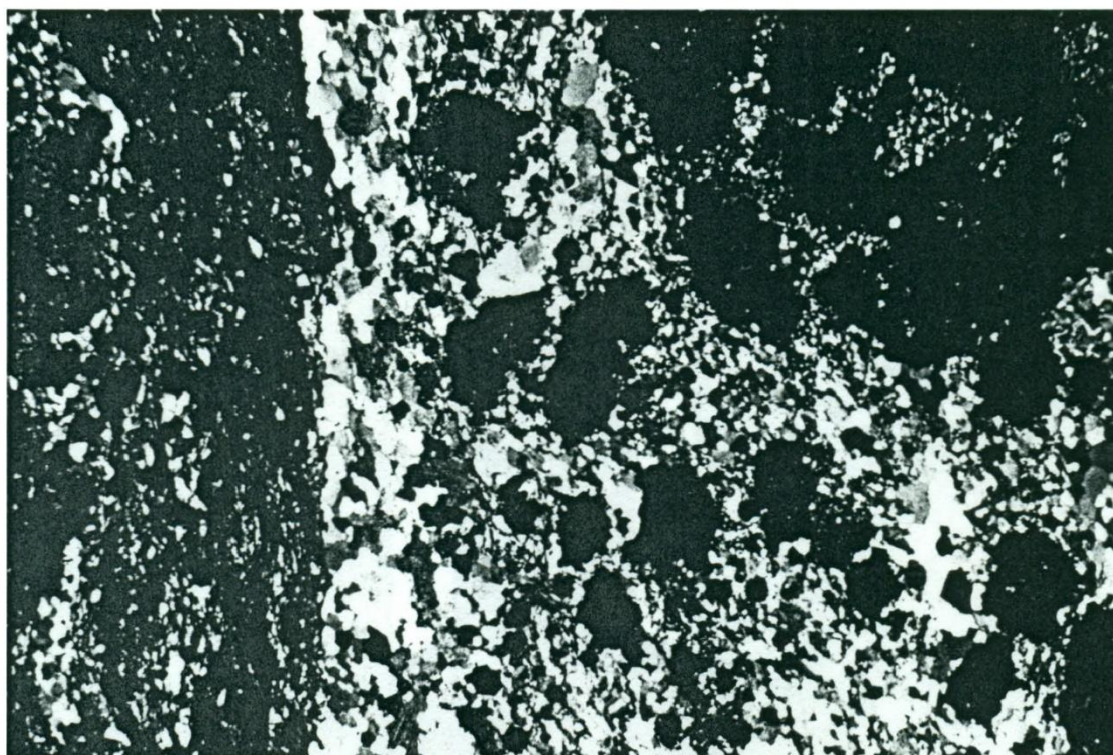


Plate 12B: Same view (289) in XPL

- **290B — Altered (tremolite-epidote-sphene-chlorite) diorite**

Igneous: Plagioclase ($\approx \text{An}_{30}$) >> possible primary quartz, no primary mafic phases preserved.

Alteration: Zoned epidote/clinozoisite > tremolite (or Fe-poor actinolite) > sphene > chlorite: some quartz veinlets.

A diorite or quartz diorite with a good coarse-grained (3-4mm) igneous texture defined by interlocking plagioclase crystals. Minor quartz occurs in finer-grained interstitial aggregates. Alteration is strong. Secondary minerals predominantly occur as irregular replacive masses with lesser “dusting” of the preserved igneous plagioclase. Chlorite occurs in small masses which may be pseudomorphs of primary biotite or amphibole. The secondary tremolite has a weak preferred orientation though the igneous texture shows no evidence of deformation.

Petrogenesis: An intrusive igneous rock of intermediate composition which has undergone Ca-metasomatism.

- **291A — Altered (calcite-biotite(?)-quartz) plagioclase rock**

Plagioclase (An_{35}) > calcite >> biotite > quartz. Thin graphitic seams and minor pyrite and a colourless, high relief isotropic mineral which may be sphalerite.

A problematical rock consisting of fine-grained granoblastic plagioclase (a metamorphic texture) with biotite-calcite-rich laminae in which the biotite has a fairly crude preferred orientation parallel to the layering. Some of the calcite occurs in veins which although in very different orientations to the laminae, do not show clear cross-cutting relationships. Quartz occurs in veinlets and as ovoid aggregates which could be derived from amygdaloids. It is not clear whether the biotite is secondary or whether the calcite alteration has preferentially affected biotite-rich compositional layers in a regionally metamorphosed rock.

Petrogenesis: Probably a meta-andesite. It could be a regionally metamorphosed rock or a hornfels.

- **292A — Clinopyroxene-epidote-magnetite “skarn”**

Green clinopyroxene (probably hedenbergite) > epidote > opaques (magnetite $\approx 15\%$) > quartz > green amphibole (hornblende/actinolite) > carbonate.

This rock has a domainal texture with variations of modal mineralogy and grain size. The main associations are 1) clinopyroxene-magnetite, 2) epidote-clinopyroxene-quartz-magnetite, and 3) coarse clinopyroxene which occurs around coarse-grained quartz patches. There is no planar fabric which can be ascribed to the regional metamorphism.

Petrogenesis: Mineralogy and texture indicate a metasomatic rock - protolith uncertain.

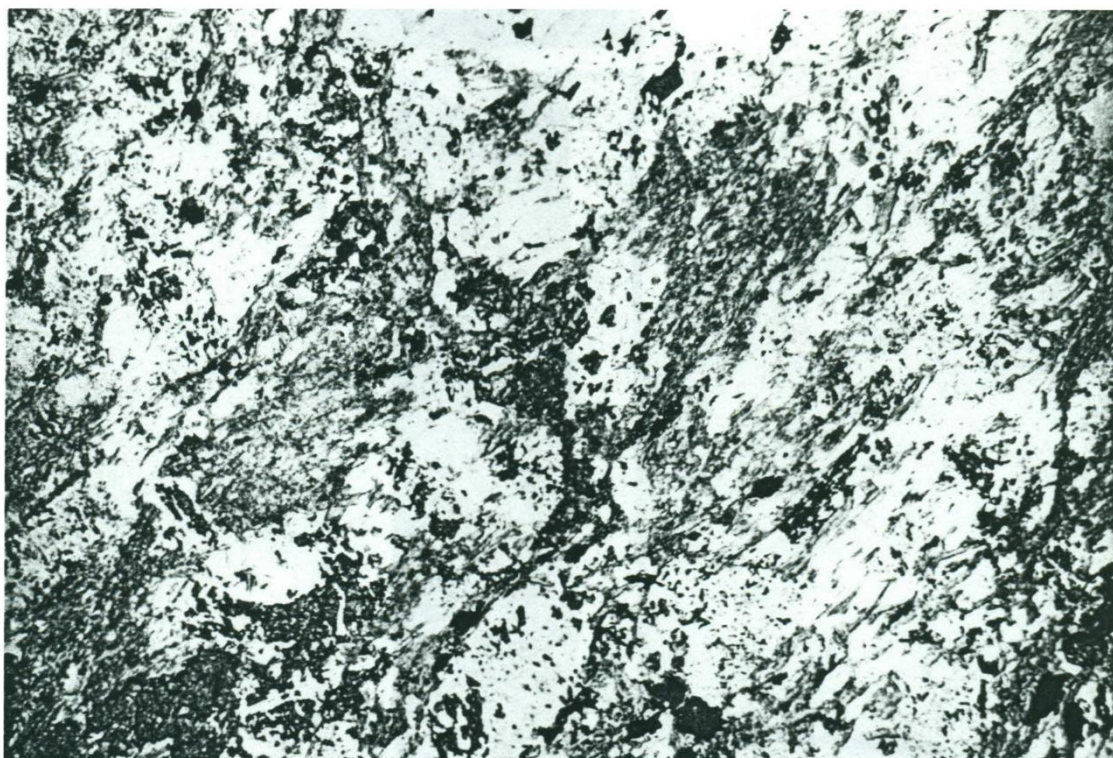


Plate 13A: Altered diorite (290) with secondary sphene (high relief/black), epidote (strong relief- bottom left) and tremolite (moderate relief) - PPL field of view 8mm.



Plate 13B: Same view in XPL showing relict twinned plagioclase and igneous texture

- **292B — Epidote “skarn”**

Epidote (minor clinozoisite) >> quartz $\approx$ calcite $\approx$ pyrite $\approx$ chlorite >> tremolitic amphibole, accessory sphene.

Massive medium-coarse grained granular epidote and accessory fine-grained sphene without obvious fabric elements. The epidote is cut by veinlets of quartz and calcite which locally contain small amounts of a tremolitic amphibole and pyrite. These in turn are cut by later and narrower veinlets of chlorite, carbonate and minor quartz. Pyrite has alteration selvages of chlorite.

Petrogenesis: The simple primary mineralogy and composition indicate that this is a metasomatic rock - protolith uncertain.

- **293 — Quartz-muscovite-albite schist**

Quartz > muscovite > sodic plagioclase >> colourless amphibole (probably tremolite) > opaques ($\approx$ 1%). Accessory sphene, apatite and tourmaline.

A compositionally layered quartz-muscovite schist whose fabric is “wrapped around” albite porphyroblasts showing that all of these minerals formed during the regional metamorphism. A fairly strong linear fabric is evident in hand specimen. Small amounts of tremolite occur and the crystals tend to lie parallel to the schistosity. Some of it however is clearly a randomly oriented alteration product of albite. The origin of the tremolite fabric is unclear and it may not be tectonic (cf. 290 and 294).

Petrogenesis: A regionally metamorphosed pelitic sediment which has undergone minor Ca-metasomatism.

- **294 — Altered (epidote-tremolite-sphene) porphyritic microdiorite**

Igneous: Plagioclase ($\approx$ An₃₀) >> quartz, no primary mafic phases preserved.

Alteration: Zoned epidote/clinozoisite $\approx$ tremolite (or Fe-poor actinolite) > sphene.

Glomeroporphyritic aggregates of altered plagioclase phenocrysts set in a fine-grained matrix of plagioclase with very minor quartz. The matrix is more extensively altered than the phenocrysts and the alteration products are generally finer-grained than those in the similar rock, 290. The secondary tremolite has quite a strong preferred orientation which gives the rock a weak fabric though it is not clear if this is a tectonic feature.

Petrogenesis: An intermediate igneous rock, probably from a high-level intrusion, which has undergone Ca-metasomatism.



Plate 14A: Epidote skarn (292B) - PPL, field of view 8mm.

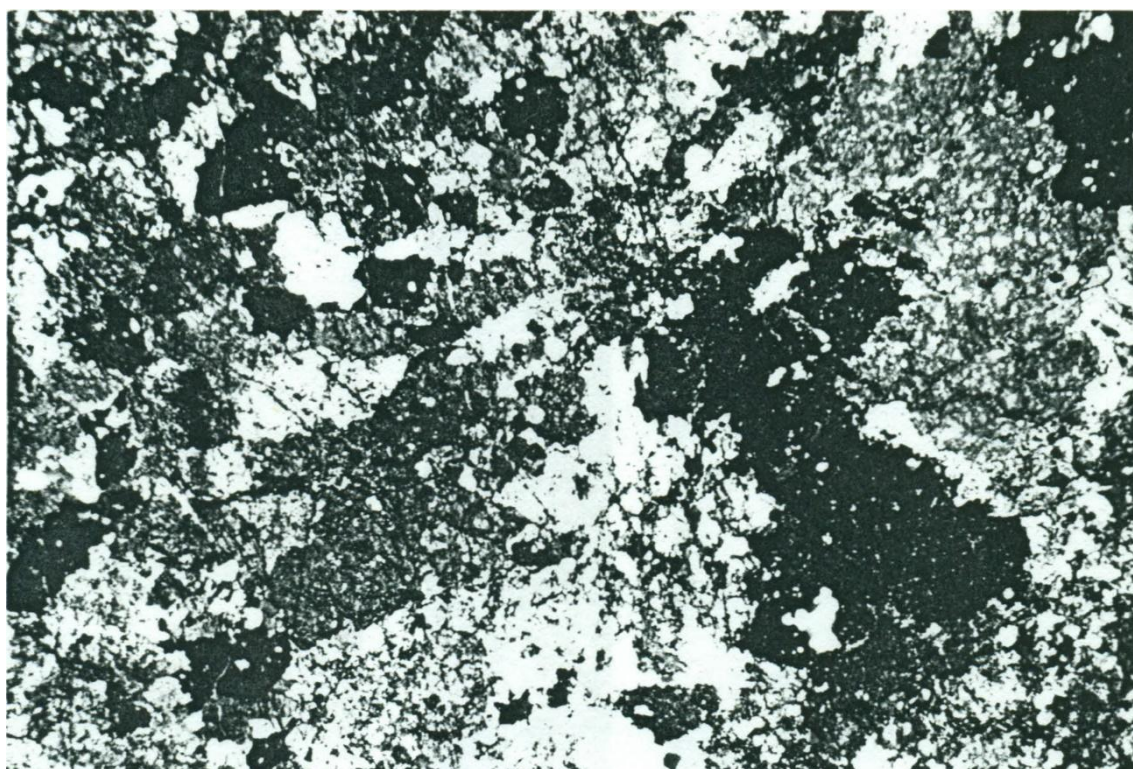


Plate 14B: Same view (292B) in XPL

4. Detailed descriptions of selected specimens

- **266 — Epidotised calc-schist**

Mineral	Approximate modal proportion %
Quartz	60
Green amphibole	5
Garnet	2
Epidote	30
Opagues (pyrite)	2
Sphalerite (?)	<1

Quartz is fine-grained (≈ 0.1 mm) and has polygonal grain morphology and granoblastic metamorphic texture. The grains exhibit a slight elongation, which together with the preferred orientation of amphibole prisms define a schistosity. The amphibole is green in thin section and could be either actinolite or hornblende. A compositional layering parallel to schistosity is defined by variations in the relative proportions of amphibole and quartz and also by the presence of laminae containing tiny salmon-pink garnets. There are also a few garnet porphyroblasts (up to ≈ 1 mm) which are wrapped-around by the schistosity. Thus, the garnet, amphibole and most of the quartz in this rock crystallised during a phase of regional metamorphism. The calcic amphibole and garnet suggest that this assemblage represents a metamorphosed impure (calcareous) siliceous sediment.

Epidote occurs largely as irregular masses which are semi-concordant to the metamorphic fabric and exhibits extreme variation of grain size (< 0.01 mm up to ≈ 1 mm). The larger grains have marked compositional zoning and some of them include small proportions of reddish-brown material which is probably the manganiferous variety, piemontite. The presence of veinlet-like masses of epidote which are strongly discordant to the schistosity, and also a local association with coarse-grained vein quartz, suggest that this mineral is secondary (i.e. post-regional metamorphism). It is however possible that some fine-grained epidote which occurs as isolated grains associated with quartz and amphibole, may be part of the regional metamorphic assemblage. (The replacive nature of much of the epidote is more obvious in the hand specimen.)

Xenomorphic to subidiomorphic opaques (apparently mostly pyrite) occur as disseminations but are relatively concentrated in small volumes of the rock. A brown, high relief, isotropic mineral taken to be sphalerite occurs particularly in selvages to the larger garnets suggesting it was concentrated either towards the end of, or after the regional metamorphism. There are no unequivocal indications of the precise place in the paragenesis of the sulphides.

Petrogenesis: A regionally metamorphosed calcareous and argillaceous sandstone or chert which underwent epidote-quartz alteration after the formation of the ductile fabric.

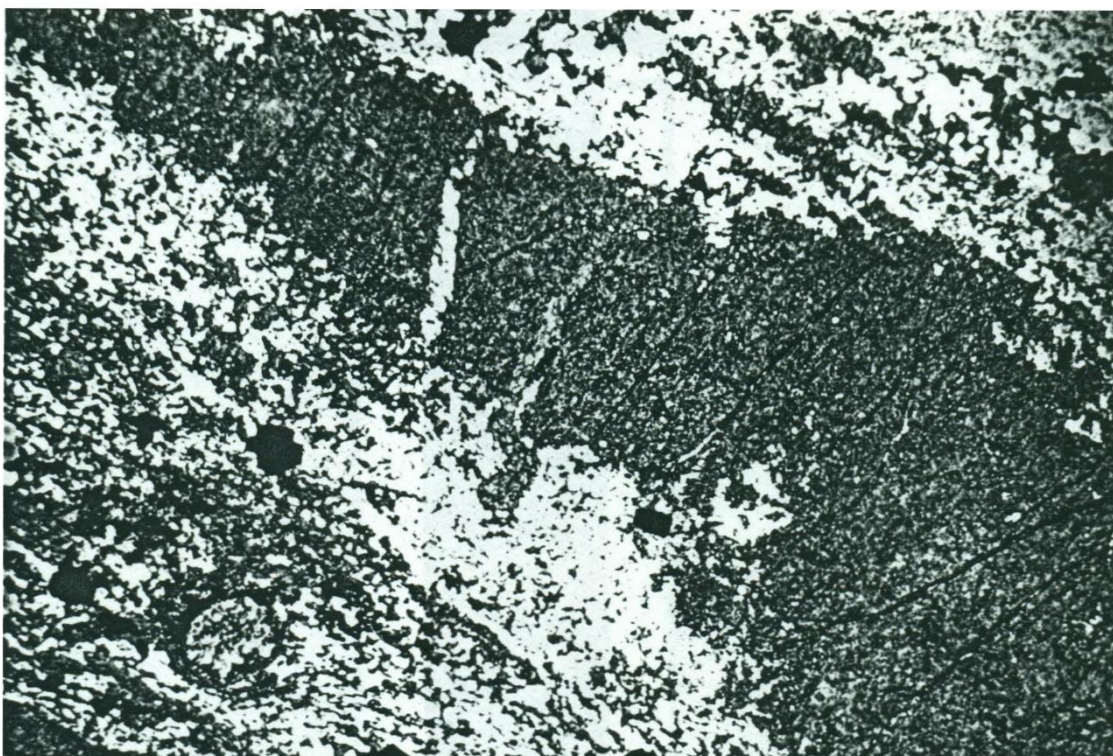


Plate 15A: Epidote replacement (top left - bottom right) of calc-silicate schist (266) – PPL, field of view 8mm.



Plate 15B: Replacive epidote patch in calc-silicate schist (266) with relict altered amphibole (centre) and red-brown compositional zones (probably manganiferous) - PPL, field of view 3.5mm.

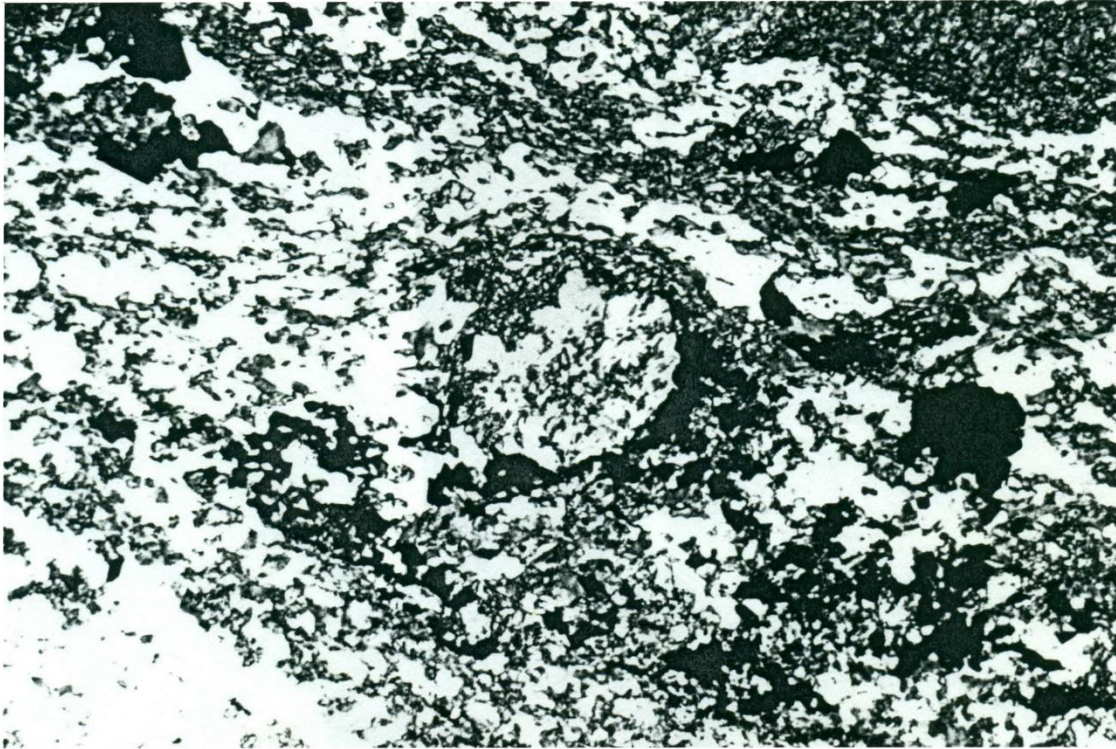


Plate 15C: Regional metamorphic garnet porphyroblast in calc-silicate schist (266) wrapped around by amphibole fabric and associated with sphalerite (?opaque)-PPL, field of view 3.5 mm.

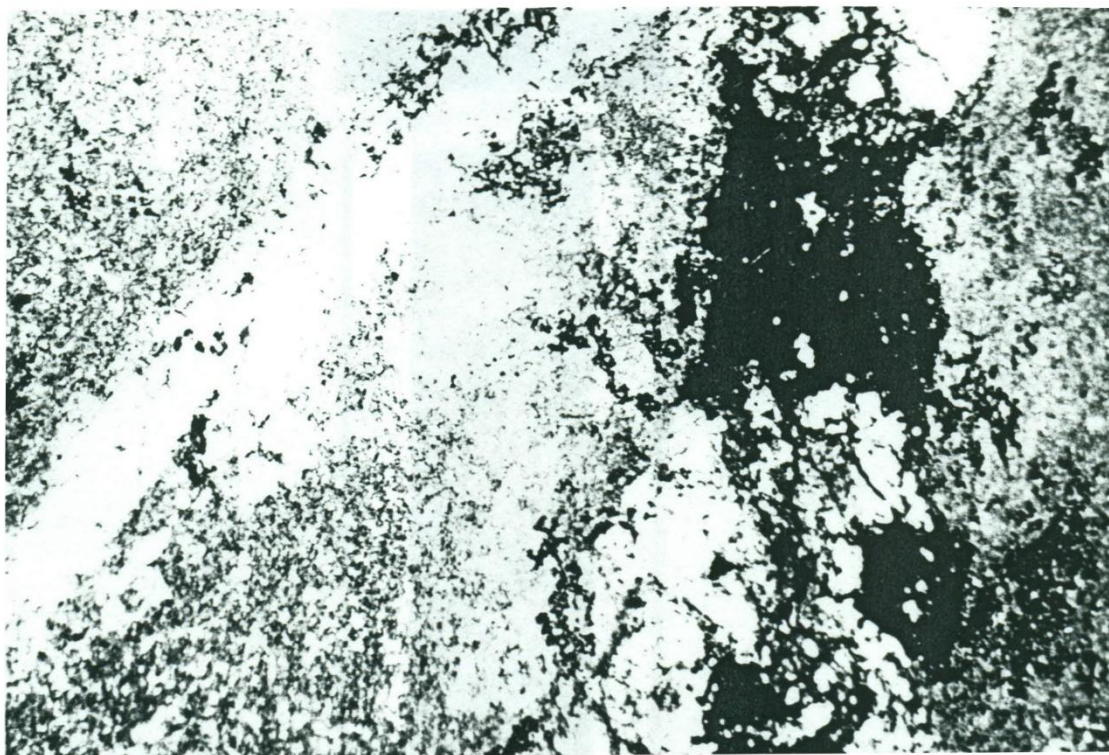


Plate 16A: Epidote-garnet vein (left), epidote-pyrrhotite vein (right) and garnet porphyroblasts in altered amphibolite (267A) - PPL, field of view 8mm.

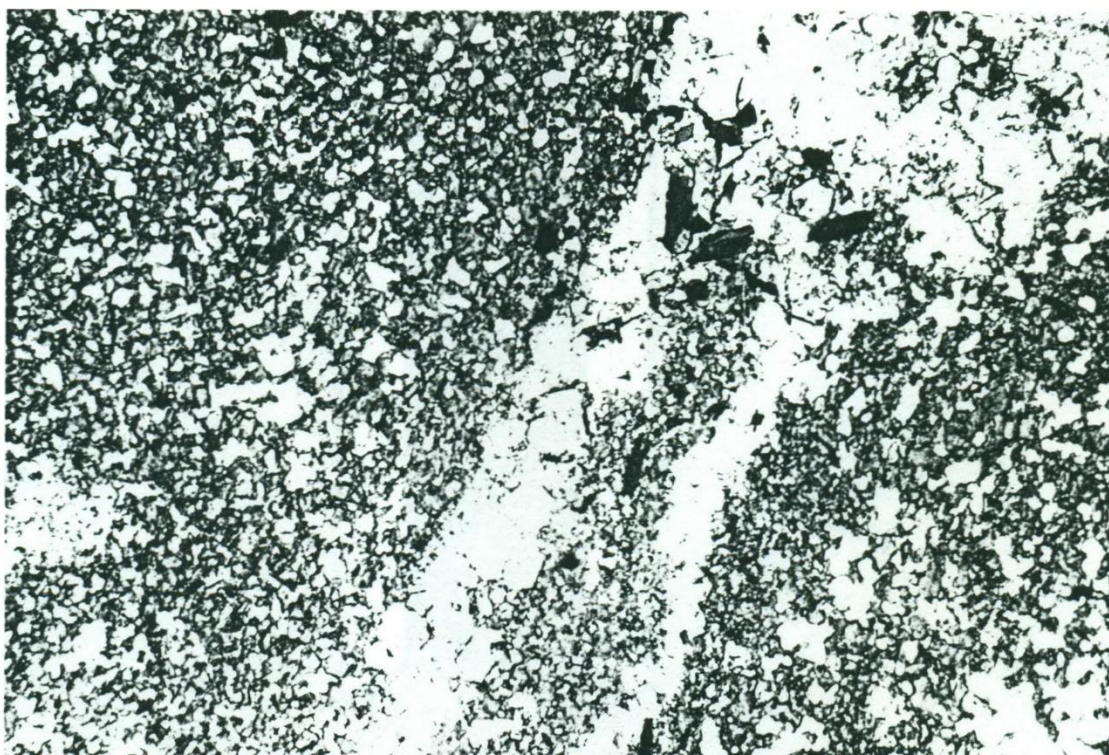


Plate 16B: Garnet-epidote veins associated with dark amphibole in altered amphibolite (267A) - PPL, field of view 3.5mm

- **267A — Altered (Ca-garnet-epidote-pyrrhotite-amphibole) amphibolite**

Mineral	Approximate modal proportion %
Host rock	
Green amphibole (hornblende/actinolite)	50
Quartz 1	10
Sphene	trace
Alteration	
Ca garnet	20
Epidote	10
Quartz 2	1
Dark green amphibole (ferroactinolite?)	1
Carbonate	trace
Pyrrhotite	7
Chalcopyrite	trace

The host rock is a fine-grained amphibolite with a compositional layering defined by variations in the relative proportions of amphibole and quartz. The amphibole grains have a preferred orientation which gives the rock a metamorphic fabric parallel to the layering. This fabric is quite weak because the amphibole grains have for the most part, a fairly “stubby” habit.

The alteration is texturally complex. Garnet shows anomalous anisotropy indicating that is a calcic variety. It occurs in two textural settings. The first of these is as zoned, subidiomorphic porphyroblasts ($\approx$ 1-2 mm) which are set in the amphibolite and which are relatively concentrated in certain parts of the rock. The porphyroblasts contain inclusions of the host-rock amphibole and have grown in two stages. They are characterised by near colourless, strongly (birefringence)-zoned cores surrounded by orange coloured near isotropic rims. The latter material is optically similar to the second form of garnet which occurs as relatively small grains in veins in which it is associated with epidote, sulphides and small amounts of secondary quartz and carbonate. Epidote is the dominant mineral in these veins and the sulphides, quartz and carbonates appear to have been introduced at a slightly later stage than the crystallization of the epidote-garnet association. Sulphides are relative concentrated in partly-replaced selvages around these veins (i.e. in the host amphibolite) and locally have invaded fractures in the garnet porphyroblasts. These selvages are also characterised by the development of a second form of amphibole which is very strongly coloured and pleochroic. It is assumed to be Fe-rich (possibly ferroactinolite) and commonly has a needle-like habit, particularly where it is intergrown with pyrrhotite. The sulphide assemblage consists almost entirely of pyrrhotite which is locally intergrown with very small amounts of chalcopyrite. There are no oxide minerals in the rock.

Petrogenesis: A regionally metamorphosed basic rock which underwent 3 stages of alteration after the development of the ductile fabric. These involved, 1) Ca-metasomatism forming Ca garnet porphyroblasts, 2) A second phase of Ca-metasomatism forming epidote-garnet veins and overgrowths on the earlier porphyroblasts, and 3) Introduction of pyrrhotite-chalcopyrite-quartz-carbonate into and around stage 2 veins associated with the formation of an Fe-rich amphibole in the altered vein selvages

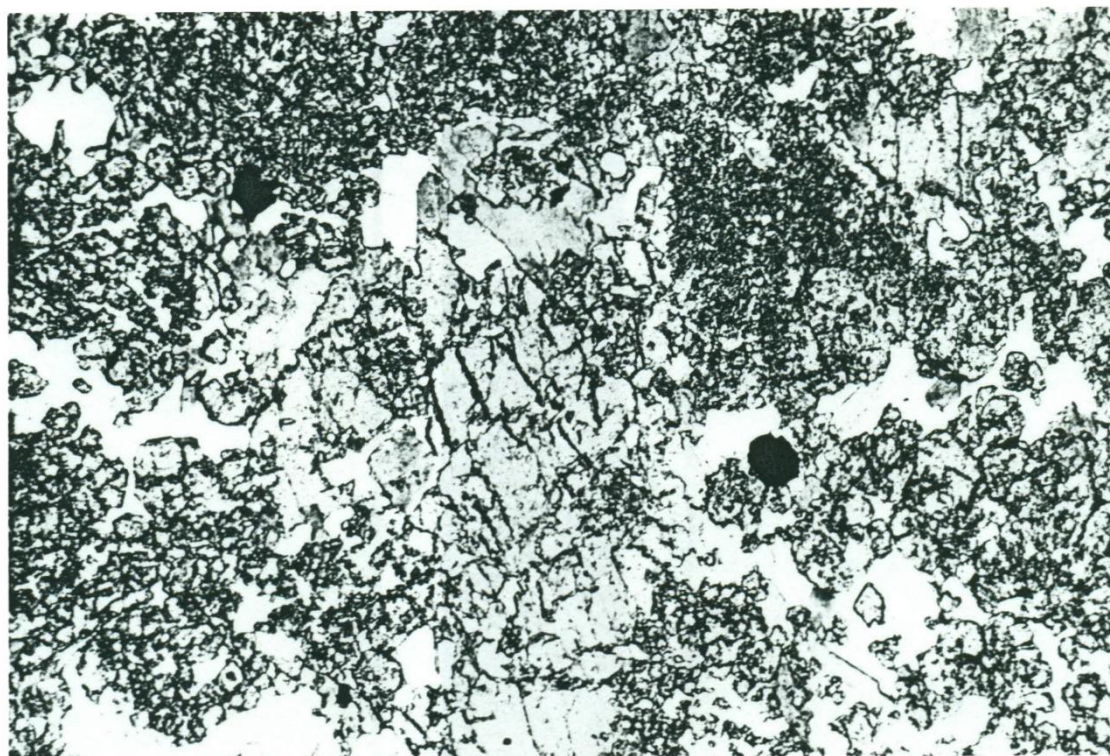


Plate 17A: Clinopyroxene (centre)-amphibole (smaller bluish green grains)-garnet- epidote-quartz skarn (285A) -PPL, field of view 3.5mm

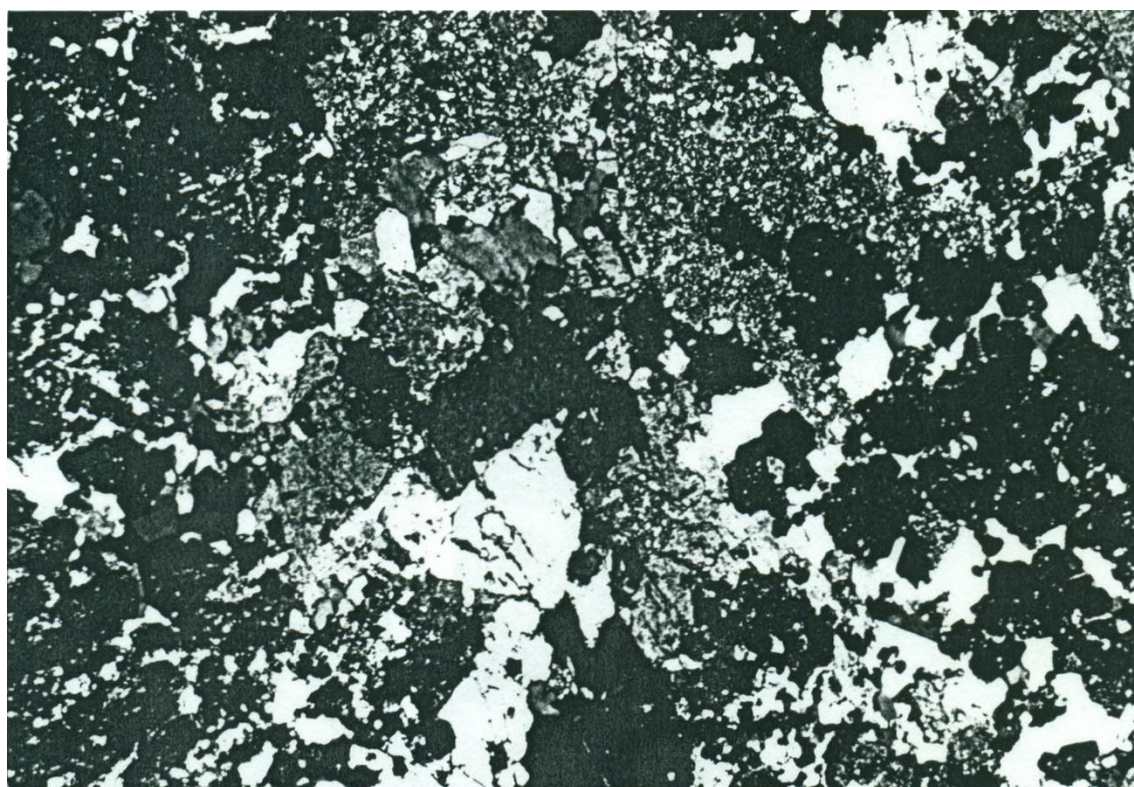


Plate 17B: Same view (285A) in XPL

- **285A — Grossularite-clinopyroxene-amphibole-epidote “skarn”**

Mineral	Approximate modal proportion %
Garnet	40
Green clinopyroxene	10
Green amphibole	5
Epidote	15
Calcite	10
Quartz	20
Opakes	1

Garnet shows anomalous anisotropy (usually characteristic of Ca garnets) and has a pink-white colour in hand specimen suggesting that it is grossularite. It occurs as aggregates of fine-grained subidiomorphic grains and also as sieve-textured porphyroblasts with abundant inclusions, predominantly of calcite. Garnet is compositionally zoned and there are discrete small grains and zones in larger grains with a strong brownish colour which may be more Fe and/or Mn-rich. The clinopyroxene is dark in hand specimen and has a strong green colour in thin section suggesting that it is hedenbergite. It also occurs as poikilitic grains (up to ≈ 2 mm) with inclusions of quartz, amphibole and calcite. The amphibole is green in thin section and may be either actinolite or hornblende. In addition to the inclusions, quartz, calcite and amphibole occur as interstitial aggregates to the garnet and clinopyroxene. There are some patches of almost pure granoblastic quartz several mm in size. Epidote has a patchy distribution and some of it occurs with calcite in veins which clearly post-date the other minerals. Opaque minerals are disseminated throughout the rock and show no particular relationship to the veins.

This rock has a heterogeneous random texture and there are no features which can be unequivocally assigned to the regional metamorphism evident in other rocks of this suite.

Petrogenesis: The skarn mineralogy and lack of a metamorphic fabric suggest that this is a metasomatic rock. There is no direct evidence of its protolith.

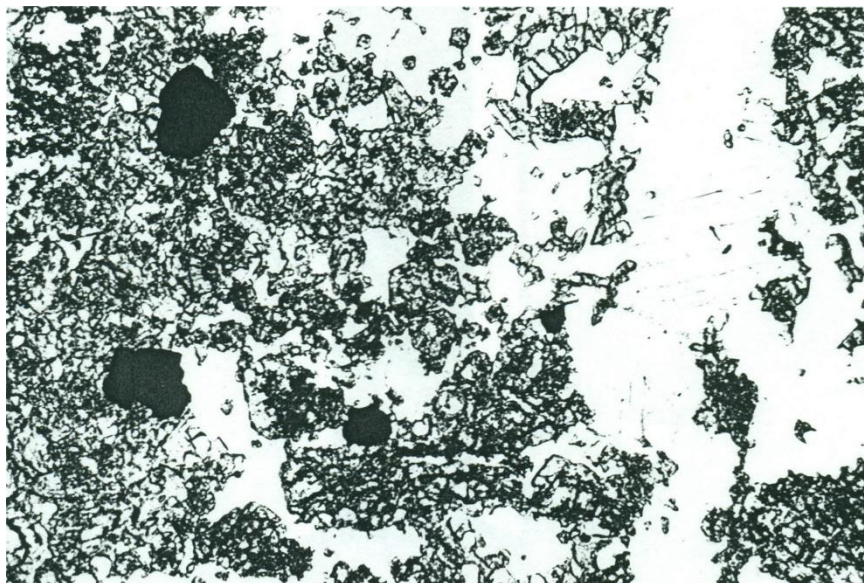


Plate 17C: Late calcite veinlet cutting skarn (285A) - PPL, field of view 3.5mm

- **286G —Altered (epidote, Ca garnet, magnetite)**

Mineral	Approximate modal proportion %
Green amphibole (hornblende/actinolite)	55
Epidote	30
Ca garnet	5
Quartz	3
Carbonate	trace
Magnetite	5
Pyrite	trace
Chalcopyrite	trace

A medium-grained amphibole schist. The relict amphibolite fraction is near monomineralic and the prismatic amphibole grains exhibit a moderately strong preferred orientation. Semiconcordant to strongly discordant patches and vein-like replacements of Ca-rich material have a rather heterogeneous distribution. There is a textural separation of the secondary minerals in that epidote occurs as monomineralic, medium-grained aggregates; garnet in local intergrowths with quartz; and magnetite as discrete idiomorphic grains which are disseminated randomly throughout the rock (i.e. this mineral is not concentrated into any specific layers and shows no relationship to the metamorphic fabric - it is therefore assumed to belong to the secondary assemblage). Epidote grains show slight compositional zoning. The garnet has anomalous anisotropy which reveals slight zoning and its calcic character. It occurs as aggregates and as partial idiomorphic forms surrounded by polygonal quartz and (less commonly) carbonate intergrowths. The latter form of garnet is typically nucleated on relict clots of amphibole. Minute amounts of fine-grained pyrite occur in close association with each other and seemingly also with grains of magnetite.

Petrogenesis: A regionally-metamorphosed basic rock which underwent Ca-metasomatism and magnetite mineralization after the development of the ductile fabric.

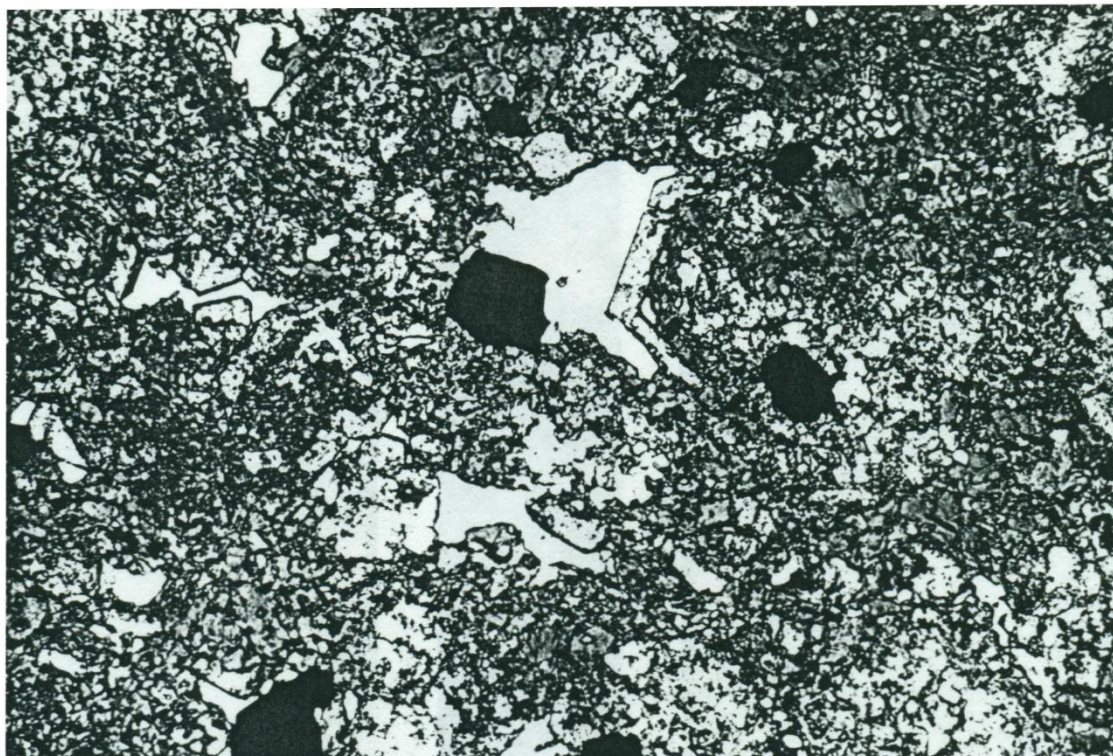


Plate 18A: Epidote (yellowish green)-clinopyroxene (green)-garnet-magnetite skarn (286G)- PPL, field of view 3.5mm.

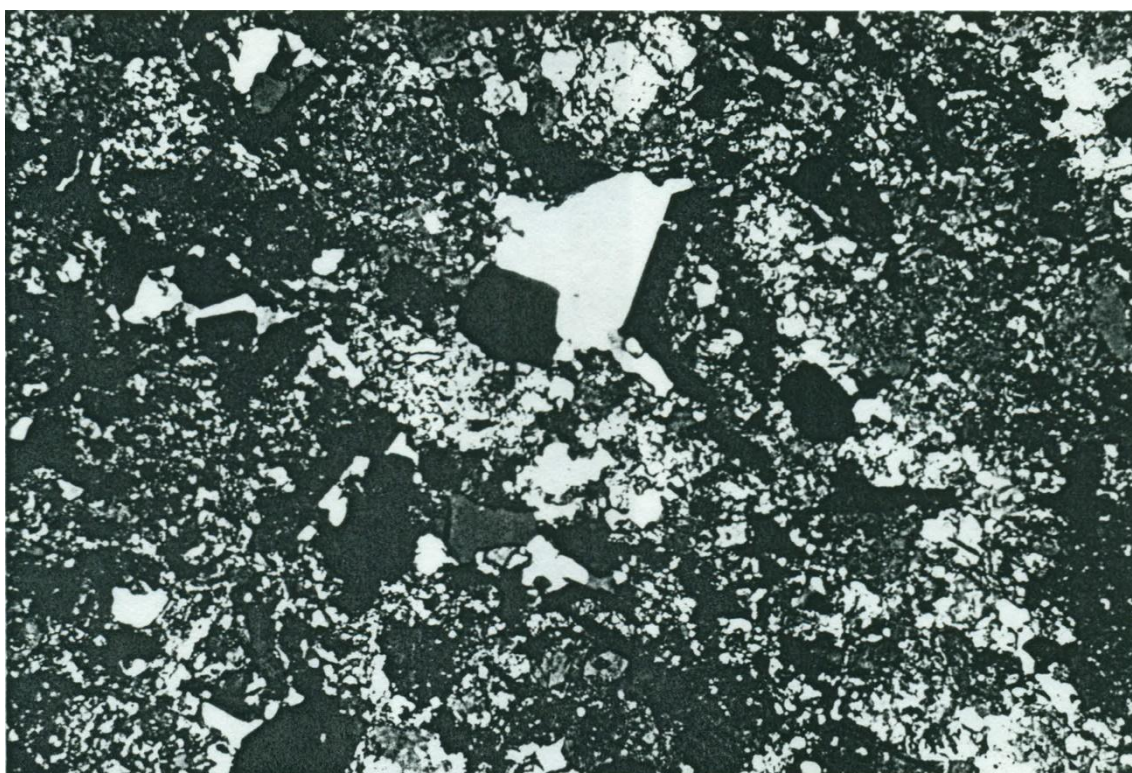


Plate 18B: Same view (286G) in XPL

- **288A — Impure siliceous marble**

Mineral	Approximate modal proportion %
Calcite	60
Quartz	25
Garnet	7
Tremolite	3
Biotite	<1
Chlorite	1
Opauques	3

A compositionally layered marble with strong modal variation involving all the essential phases. Parts of the rock containing significant quartz and/or tremolite have a schistosity defined by the grain shape and preferred orientation of these minerals. Calcite-rich layers have a more polygonal granoblastic texture. Idiomorphic net-textured garnet (salmon pink in hand specimen - not to be confused with reddish zones of weathered carbonate) occurs in aggregates of small grains which have synkinematic inclusion fabrics and which like the other essential phases must therefore belong to the regional metamorphic phase. Locally it has abundant random inclusions of carbonate which could be retrograde alteration feature. Opaque phases are concentrated in specific compositional layers and the larger grains are intergrown with the other phases in a manner which suggests they are part of the metamorphic paragenesis and that they were therefore introduced into the rock either before or during this metamorphism. There are irregular patches of extremely fine-grained opaque material which is probably graphite and which is texturally similar to that seen in specimen 280. Small amounts of chlorite occur more or less throughout the rock and some of it can be seen to be a retrograde alteration product of biotite. There are some monomineralic and relatively coarse-grained quartz veinlets and patches of unstrained quartz which show that there was a minor silicification event after the development of the ductile fabric.

Petrogenesis: A regionally metamorphosed siliceous limestone with additional argillaceous, dolomitic and carbonaceous impurities.

5. Synthesis

5.1 The lithological association

The suite of rocks from the Rio Mulatos area can be subdivided into several constitutional types including:

- (a) Igneous rocks
- (b) Regionally metamorphosed rocks
- (c) Essentially metasomatic rocks
- (d) Problematical and miscellaneous rocks

Rocks in category b exhibit variable degrees of alteration which post-dates the regional metamorphism (see below) and there is probably a complete gradation between categories b and c. Rocks described here as essentially metasomatic are those whose mineralogy and texture are deduced to be entirely secondary. Category d includes various rocks which cannot be placed in either category b or c with total certainty and also the serpentinite (specimen 261) whose status with respect to the other rocks is unclear.

(a) Igneous rocks

Two of the specimens are igneous rocks (290 & 294). Both are intermediate in composition, being diorites or quartz diorites and while the igneous minerals are strongly altered, primary textures are preserved in both cases (Plate 13). Specimen 290 is a fairly coarse-grained equigranular rock of undoubted intrusive origin whereas specimen 294 is a porphyritic fine-medium grained rock which is suggestive of an origin within a high-level intrusion.

(b) Regionally metamorphosed rocks

Most of the specimens show evidence of regional metamorphism in the form of ductile fabrics and from the presence in some cases of synkinematic porphyroblasts. The grade of the metamorphism was upper greenschist to amphibolite facies. A great diversity of compositional types is present suggesting that the protoliths included a range of clastic and carbonate sediments together with basic and possibly intermediate volcanic and/or intrusive rocks. *Marbles* (specimens 268B, 280 & 288A) are predominantly calcitic and impure. They are typically siliceous and carry variable amounts of grossularite (Plate 3), tremolite and graphite (Plate 8). The latter suggests that some of the protoliths may have been organic-rich limestones. *Calc-silicate schists* also occur (e.g. specimen 266, Plate 15c) in which regional metamorphic garnet and amphibole occur with quartz and phyllosilicates. *Pelites* (e.g specimen 289 - Plate 12, and part of specimen 271B - Plate 5a) and *semipelites* (specimen 293) are also present. The pelitic rocks, like the marbles are in some cases highly graphitic (Plate 12) suggesting that these are metamorphosed black shales. There appears to be no true iron formation in the suite though it is possible, if unlikely that the abundant pyrite in specimen 265 is of sedimentary origin. Rocks containing magnetite all belong to the metasomatic suite.

Many of the rocks are *amphibolites* (Specimens 267A, part of 271B, 273, 285A, 286A, 286B and 286C). These are probably metamorphosed basic rocks but some or all of them could be derived from dolomitic marls, a possibility which might be tested if reasonably comprehensive geochemical data are available. The *plagioclase rock* (specimen 291A) may be a meta-andesite.

5.2 Alteration

Although more complex in detail, the main alteration seen in these rocks can be roughly divided into two types. These are firstly and generally earlier Ca-metasomatism expressed by replacements of minerals such as *epidote*, *Ca-rich garnet* and *tremolite*, in some cases with *quartz*. The second and typically later common form of alteration is essentially silicification expressed as *quartz* veinlets which commonly contain lesser amounts of *calcite* and in one case (specimen 286B), *adularia* and *apatite*.

Ca metasomatism has been recognised in the igneous rocks and also in the regionally metamorphosed basic, pelitic, semipelitic and calc-silicate rocks. Most of the metasomatic rocks (skarns) discussed below are likely to be extreme forms of this alteration.

The two igneous rocks (specimens 290 & 294, Plate 13) exhibit a distinctive form of alteration characterised by epidote, tremolite and sphene. Tremolite laths exhibit a preferred orientation in these rocks which gives them a foliated appearance even though the igneous textures seem undeformed.

Alteration of the metamorphic rocks is dominated by the development of secondary epidote (Plates 1, 6, 11a, 15, 16) although in some cases it appears that this mineral was preceded by Ca-garnet (e.g. in specimen 267A). The replacive nature of these calc-silicates is often more obvious on the cut surfaces of the hand specimens than it is in thin section. The garnets commonly exhibit overgrowths of more strongly coloured material (more Fe-rich and possibly andraditic) which appears to be coeval with the epidote. This may indicate that conditions became more oxidising as the Ca metasomatism proceeded. One consequence of this style of alteration is that some rocks contain two entirely different forms of garnet (i.e. regional metamorphic Fe-Al garnet and metasomatic Ca-garnet, e.g. specimen 289, Plate 12)

Veinlet silicification and carbonation affects the whole range of material present in this suite including the igneous rocks, previously Ca-metasomatised and skarns (Plates 1, 2, 4, 10, 11a, 17c). In view of the association of gold with quartz-adularia veins at Nambija it is important to note that specimen 286B contains small amounts of adularia in a late quartz vein and that the feldspar shows a close textural affinity with the opaque minerals in the rock. Others members of the 286 series contain similar quartz veinlets but these lack feldspar.

A few of the rocks contain post-kinematic *biotite* or *phlogopite* porphyroblasts which are interesting because they might represent a distinct form of K-metasomatism in the suite (specimens 265 & 273, Plates 1 and 6).

This current investigation has not encompassed a detailed study of the ore mineralogy of these rocks. However, it would appear from the limited data available that in most cases sulphides (pyrrhotite, pyrite and chalcopyrite) were introduced during the interval spanning the later (epidote) part of the Ca-metasomatism and the later vein development. Two rocks (specimens 266 & 280) contain a high relief, isotropic mineral which is believed to be sphalerite and whose paragenesis is uncertain.

(c) Metasomatic rocks

With one exception (the tourmalinite, specimen 269B) all the rocks classified here as metasomatic are composed predominantly of Ca-rich silicates and can be termed “skarns”. As has been stated above, they would appear to be extreme products of Ca-metasomatism. The skarns exhibit a great range texture and composition. Polyminerale skarns include examples with variable proportions of *epidote*, *Ca-garnet*, *amphibole*, a *green clinopyroxene* (taken to be hedenbergite) with or without *magnetite*, *carbonate* and *quartz* (Plates 9, 17 and 18). These rocks are characterised by an absence of regional metamorphic fabrics but may have layered or domainal textures defined by grainsize and modal variations. Essentially monomineralic skarns also occur and include *diopside skarn* (specimen 274, Plate 7), *epidote skarn* (specimen 292B, Plate 14) and *clinozoisite skarn* (specimen 267H, Plate 2). The diopside skarn is unique in this suite as it is the only rock with a highly magnesian composition.

The suite includes several problematical rocks which may be skarns or only partially modified metamorphic rocks. These include the clinopyroxene-epidote-amphibole rocks (specimen 286C-E, Plate 11b) and the quartz-grossularite rock (specimen 285C, Plate 10).

The tourmalinite (specimen 269B, Plate 4) is a distinctive metasomatic rock which indicates that the sequence must locally have been infiltrated by B-rich fluids. This may be significant as such alteration is more usually found in association with granitic rocks of more evolved composition than the diorites which have been sampled. More silicic intrusions may therefore be present in the area.

5.3 General interpretation

The character of the alteration, skarns and composition of the igneous rocks in this suite, all suggest that it is an example of a calcic-magnetite skarn association (in the sense of Einaudi et al., 1981, Economic geology 75th Anniversary Volume, pp. 317-391.) This sort of skarn is a widespread association of high level dioritic intrusions in Island Arc complexes. Although the suite as a whole is lacking in evidence for more evolved acidic intrusive activity and potassic alteration of the sort which characterises the Nambija gold deposits, there are some encouraging indications that such features may in fact be present in the district.

APPENDIX 6

Petrographic study of rocks from the Tres Lagunas granite suite

by

M. P. Atherton

Study sponsored by B. P. Petroleum (Quito)

FROM THE JANE HERDMAN LABORATORIES
DEPARTMENT OF GEOLOGICAL SCIENCES

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BROWNLOW STREET P.O. BOX 147 LIVERPOOL L69 3BX

The University of Liverpool

Judey 18th December

Dear Bruce

Here, a little late, due to
our work on new studies re the new structures
on University Geology departments, are my thoughts
on the Ecuadorian granites. They are I must say
very interesting and clearly 'S' type on the
old basis/criteria. However they are not
strongly peraluminous and look like some of
the Lockian belt types which may well be
crustal melts but may not have formed
in a collisional setting as might be implied
by their 'S' type character. Indeed the Lockian
granites appear to have formed on craton.

I trust this helps.

Yours truly

Michael Atkinson

Friday 18th December

Dear Mike,

Here, a little late, due to our work on our status of the new structure on University Geology departments, are my thoughts on the Ecuador granites.

They are I must say very interesting and clearly 'S' type on the old basis/criteria. However, they are not strongly peraluminous and look like some of the Lachlan belt types which may well be crustal melts but may not have formed in a collisional setting as might be implied by their 'S' type character. Indeed, the Lachlan granites appear to have formed on craton.

I trust this helps.

Yours sincerely,

Michael Atherton

Viernes 18 de diciembre

Estimado Mike,

Aquí te envío, un poco tarde debido a nuestro trabajo sobre la nueva estructura de los departamentos de Geología de la Universidad, mis reflexiones sobre los granitos de Ecuador.

Debo decir que son muy interesantes y claramente de tipo 'S' bajo los criterios antiguos. Sin embargo, no son fuertemente peraluminosos y se parecen a algunos de los tipos del cinturón de Lachlan, que bien podrían ser fundidos de la corteza, pero podrían no haberse formado en un entorno de colisión, como podría implicar su carácter de tipo 'S'. De hecho, los granitos de Lachlan parecen haberse formado sobre un cratón.

Espero que esto ayude.

Atentamente,

Michael Atherton

Granites from Ecuador

The four 'granitoid' specimens contain the same mineral assemblage viz quartz, K-feldspar, plagioclase, biotite with minor garnet, chlorite, muscovite, epidote, sphene and ore. Two of the specimens show evidence of strong deformation: mortar texture in the quartz, where large strained quartz grains are surrounded by small annealed quartz e.g. boundary polygonization. Large biotite phenocrysts are also deformed and strained. The feldspars show much less evidence of deformation although they are frequently cracked.

In all four rocks **biotite** is large with sagenitic networks of rutile; it is brown rust coloured and looks as though it has been decolourised. It is texturally early, often showing beautiful pseudohexagonal form and has pleochroic haloes as well as inclusions of ore and apatite. It is often chloritised.

Plagioclase forms large phenocrysts with characteristic sericitization in the internal parts of the crystal while the outer part is less/not altered (albitic?). In contrast the K-feldspar which is perthitic, is almost unaltered. It occurs as large crystals, contains small inclusions of rectangular plagioclase and is not a late mineral in the crystallization sequence. It occasionally contains euhedral biotite.

Muscovite occurs as a sericitic alteration of plagioclase, and more rarely as large flakes or in association with chlorite in an apparent overgrowth texture. **Garnet** is present as euhedral grains often in clusters, confined to plagioclase where it occurs 'after' the sericitization. It often occurs with late zoisite/epidote.

Epidote/Zoisite is present as small prismatic crystals or masses in altered plagioclase; occasionally as radial growths associated with garnet. It appears to result from Ca-plagioclase breakdown and may also replace biotite.

Sphene is present invariably as an alteration product of ore which it surrounds. It is not present as a primary mineral. The ore is probably **ilmenite** as it often forms long prismatic crystals.

General

Modes for two of the rocks plot close to the boundary between granodiorite and adamellite on a Qz-Kf-Plag diagram. They lie just in the field of 'S' type granites of the Lachlan Fold Belt, Australia (Chappell and White). The absence of hornblende, the abundance of red foxy biotite with pleochroic haloes, the absence of primary sphene and the presence of muscovite and garnet, and secondary sphene after ilmenite are all indicative of an 'S' type granite. However, the garnet and epidote are both secondary and relate to the breakdown of Ca-rich plagioclase. These granitoids have suffered strong deformation and metamorphism, i.e. the peraluminosity as indicated by garnet and muscovite is mainly secondary. The rocks are therefore only mildly peraluminous on the basis of mineralogy. They do not look like classic Peruvian 'I' types, but appear to be 'S' types, slightly peraluminous without cordierite as required from the latest classification. To firmly establish their geo-tectonic setting which may not be absolutely possible it would be necessary to look at the more basic members of the lineage and do some geochemistry.

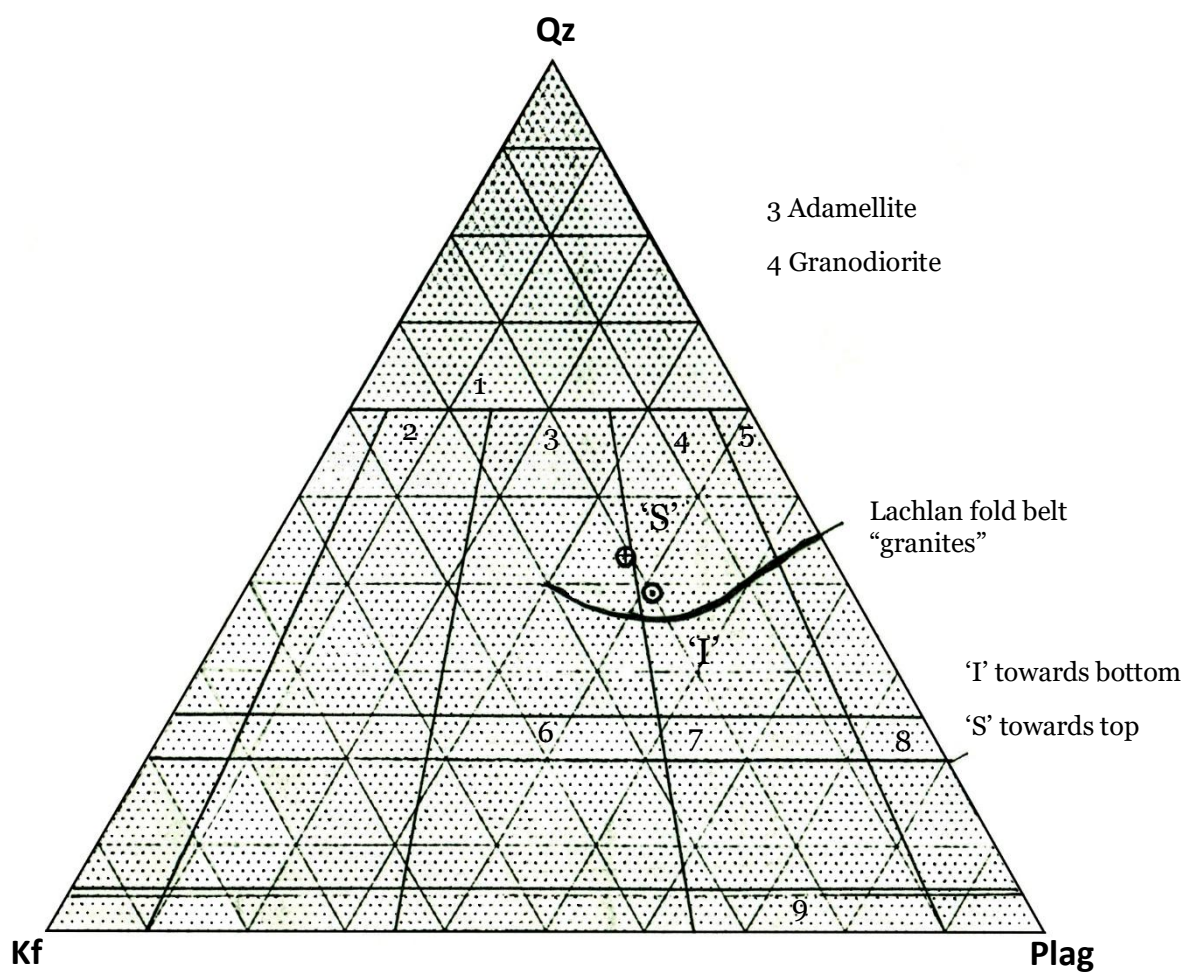
M. P. Atherton

December 1987

Samples studied

CR-FV-330	Tres Lagunas pluton
CR-FV-333-A	Tres Lagunas pluton
CR-FV-331	Peggy Mine outcrops/blocks
CR-FV-332	Peggy Mine outcrops/blocks

Modified Streckeisen diagram



APPENDIX 7

Fluid inclusion studies on rocks from the Nambija area and
Portovelo

by

T. J. Shepherd
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Fluid inclusion studies on rocks from the Nambija area and Portovelo

by

Dr. T. J. Shepherd

I made polished thin wafers of the following samples:

Location	Sample
Nambija/Guaysimi	JA1
	JA2
	JA3
	JA4
	JA5
	JA6
	JA7/1
	JA7/2
	JA8
	JA9
Portovelo	JA10
Nambija	JA11

Of these only JA2, JA6, JA7/2, JA9 and JA10 contained inclusions suitable for thermometric analysis. The remaining samples were either tectonized, in which case the inclusions had been seriously deformed or ruptured, or the inclusions were less than 2 microns. It is evident though that the garnets (i.e. JA2, JA6, JA8 and JA9) are completely devoid of liquid inclusions. Quite a surprise given the work reported by other skarn researchers. I have no ready explanation but I am certain liquid inclusions never existed in these crystals. Fluid inclusions occur exclusively in the quartz and calcite. They are typically 2 phase liquid + vapour types which homogenise into the liquid phase except for those in JA10 where some homogenise into the vapour phase or show critical homogenisation. The best inclusion material is the quartz which overgrows the zoned garnets and the late-stage calcite infilling. I have complete descriptions for each sample but I will only report here the thermometric results for JA2, JA6, JA7/2, JA9 and JA10 (see enclosed table).

As you expected JA10 is the odd ball. In the quartz the inclusions are generally fracture controlled, that is to say they occupy short, discontinuous, healed fractures. By definition this makes them secondary, but in view of the fact that they don't occur in the garnets I am of the opinion that they are intimately associated with the deposition of quartz or events immediately following (prior to the deposition of calcite). From the TH vs. salinity plot you will see that the fracture-controlled inclusions fall within a restricted field: 150-210°C, 2-11 wt % NaCl equivs. However, some of the quartz crystals show very prominent growth zoning and the inclusions which decorate these zones, although ragged, (a normal mode of development for this type of material) have much higher salinities and don't show much variation in temperature: 150°C, 17-25 wt % NaCl equivs. Of course this is all based on evidence from JA6. If we now take the calcite data you can see that the fluid conditions are almost identical to those operating during the precipitation of quartz. Thus, if the gold is related to fractures in the quartz but predates the calcite, then the deposition of gold correlates with the introduction of higher temperature/lower salinity fluids.

JA10 provides prima facies evidence that the fluids were boiling during the deposition of the quartz - just check this out by looking at the data table.

Table 1. Fluid Inclusion data for samples JA2, JA6

Sample No.	Type inclusion	Tfm °C	Tlm °C	Th °C	Salinity Eq. wt.% NaCl	Comments
JA2-quartz	2 ph, aq	-30	-1.9	177	3.2	all fracture-controlled, elongated
		-30	-1.0	189	1.8	blocky
		-30	-1.3	209	2.2	blocky, equant
		-30	-1.8	213	3.0	planar, irregular
		-30	-2.8	185	4.6	
		-28	-1.1	197	1.9	planar, elongated
		-29	-0.9	202	1.6	planar, elongated
				192		planar, elongated
		-25	-5.1	172	8.1	blocky, irregular
			-2.1	199	3.5	blocky, irregular
		-25	-2.3	171	3.9	large, irregular
		-25	-2.2	180	3.7	large, irregular
JA6- quartz	2 ph, aq		-1.4	148	2.4	all fracture-controlled, regular
			-3.4	178	5.5	all fracture-controlled, regular
			-3.3	159	5.4	all fracture-controlled, regular
			-2.5	150	4.2	all fracture-controlled, regular
			-1.4	168	2.4	all fracture-controlled, regular
			-1.4	176	2.4	all fracture-controlled, regular
			-7.0	162	10.6	all fracture-controlled, regular
			-6.5	165	10.0	all fracture-controlled, regular
			-7.3	148	11.0	all fracture-controlled, regular
			-2.2	164	3.7	all fracture-controlled, regular
		-40	-15.0	148	18.9	all in outer growth zones, irregular
		-40	-13.6	145	17.6	all in outer growth zones, irregular
		-40	-21.7		23.6	all in outer growth zones, irregular
		-40	-13.0	150	17.1	all in outer growth zones, irregular
		-46	-24.3	133	25.1	all in inner growth zones, irregular P
		-46	-19.5	145	22.2	all in inner growth zones, irregular P
		-46	-20.3	148	22.7	all in inner growth zones, irregular P

Table 2. Fluid Inclusion data for samples JA7/2, JA9, JA10

Sample No.	Type inclusion	Tfm °C	Tlm °C	Th °C	Salinity Eq. wt.% NaCl	Comments
JA7/2-late calcite	2 ph, aq	-56	-15.7	144	16.8	large, isolated
		-56	-12.3	169	13.4	large, isolated
		-56	-20.9	154	23.1	large, isolated
				141		
				170		
JA9-late calcite	2 ph, aq	-56	-14.7	153	15.8	isolated, blocky
		-56	-14.4	148	15.5	isolated, blocky
				138		isolated, blocky
				144		isolated, blocky
		-56	-13.5	148	14.6	isolated, blocky
		-56	-13.8	150	15.0	isolated, blocky
		-40	-18.2	142	21.3	isolated, blocky
		-40	-17.3	144	20.6	isolated, blocky
		-40	-15.8	143	16.9	isolated, blocky
				145		isolated, blocky
		-40	-16.4	140	17.5	isolated, blocky
		-40	-17.1	155	20.5	isolated, blocky
JA10-quartz	2 ph, aq		-1.5	345	2.5	isolated, regular
				344		L+V→L
				351		L+V→L
				361		L+V→L
				360		L+V→V
				368		L+V→V
				367		L+V→V near the critical point
				360		L+V→L
				361		L+V→V near the critical point
			-4.6	324	7.4	L+V→V near the critical point
				320		L+V→V near the critical point
				326		L+V→V near the critical point
				342		L+V→V near the critical point
				343		L+V→V near the critical point
				334		L+V→V near the critical point
				336		L+V→V near the critical point
				357		L+V→V near the critical point
				353		L+V→V near the critical point
				379		L+V→V near the critical point
				380		L+V→V near the critical point

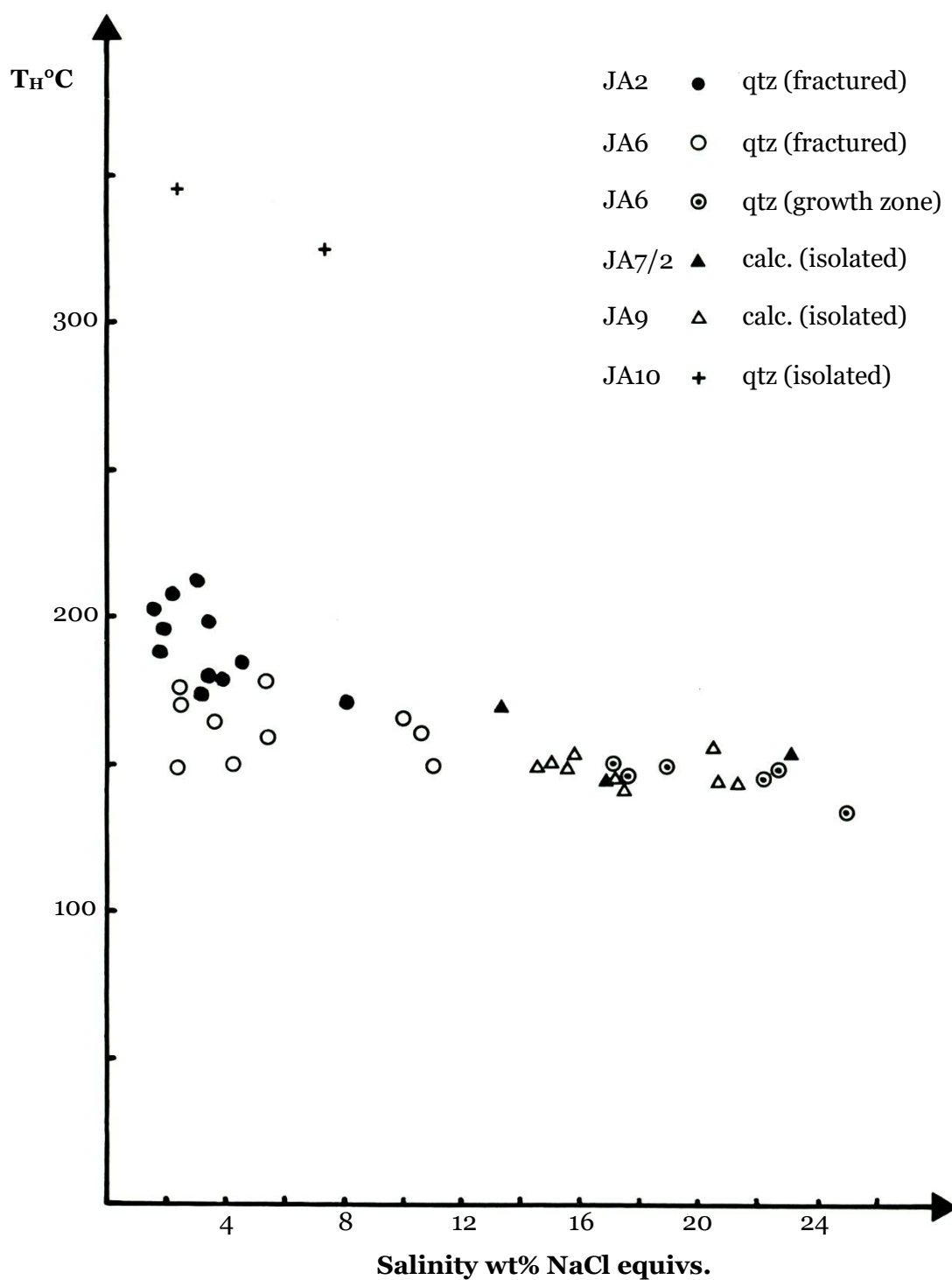


Figure 1. Salinity vs. Homogenization Temperature of fluid inclusions

APPENDIX 8

A preliminary interpretation of the collisional history of central and southern Ecuador and possible controls of Cenozoic geology and polymetallic mineralisation

A PRELIMINARY INTERPRETATION OF THE COLLISIONAL HISTORY OF CENTRAL AND SOUTHERN ECUADOR AND POSSIBLE CONTROLS OF CENOZOIC GEOLOGY AND POLYMETALLIC MINERALISATION

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(1) British Mission: Cordillera Real Project

(2) INEMIN, Gerente Técnico

1. INTRODUCTION

The paper discusses briefly the as yet undifferentiated metamorphic rocks of the Cordillera Real; the Western belt of the Cordillera Real (Aspden et al., 1987), and its proposed extension to Raspas (El Oro Province); and proposes new terranes, Chaucha-Arenillas and La Bocana, to replace those of Feininger (1987).

In contrast to the Southern and Central Andes, which are generally considered to be essentially autochthonous, (Dalziel, 1986; Cobbing, 1985) the Northern Andes of Ecuador and Colombia appear to have a long accretion history, and are therefore likely to include a high percentage of allochthonous material (McCourt et al., 1984; Aspden and McCourt, 1986; Aspden et al., 1987; Megard and Lebrat, 1986; Feininger, 1987). In this paper we present a preliminary terrane map of central and southern Ecuador. This map is based largely on our ongoing studies into the nature of the geology and economic mineral potential of the Cordillera Real but it also includes what is, in effect, a re-interpretation of the tectonic history of the metamorphic rocks of SW Ecuador.

Recently various authors have also published related studies which deal with the existence and recognition of various terranes in Ecuador (e.g. Lebrat et al., 1986; Megard and Lebrat, 1986; Feininger, 1987). This work is briefly discussed within the context of our own findings and where appropriate these results are included here in order to extend our own data base into those parts which, lie outside our current project area.

It is emphasised that the terrane map can only be regarded as being preliminary. It is by no means the final solution but rather a working hypothesis which, as more information becomes available, will undoubtedly have to be modified. However, we believe that our interpretation represents the simplest possible scenario which takes account of all the currently available geological information. As discussed later it also helps to explain a number of previously poorly understood elements of Ecuadorian geology and provides a unifying framework in which what have until now been regarded as isolated mineral occurrences can be appreciated in a more meaningful regional context.

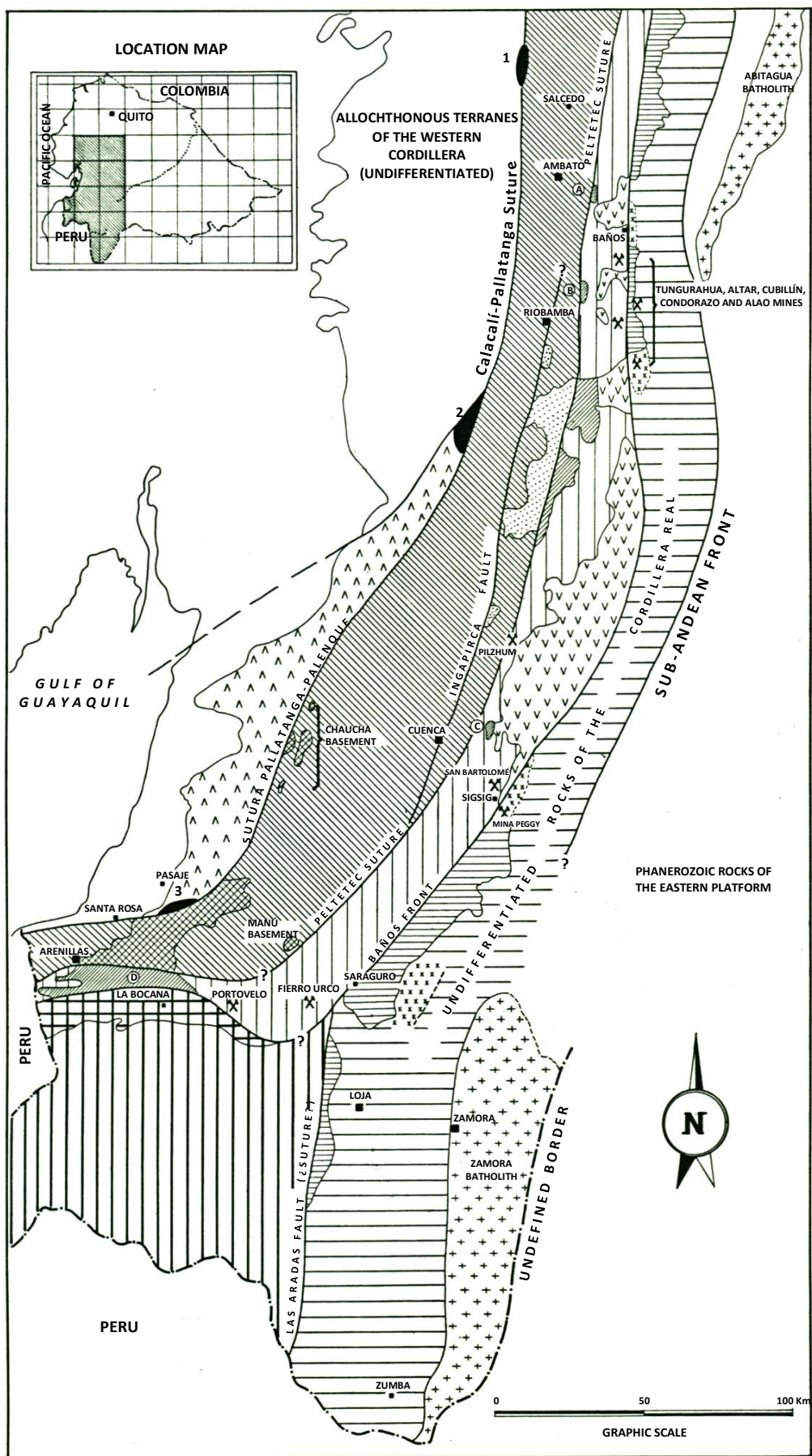


Figure 1. Preliminary map of the terranes of Central and Southern Ecuador

LEGEND

-  Predominantly undifferentiated metamorphic rocks of the Cordillera Real
-  Proposed westward extension of undifferentiated metamorphic rocks covered by younger rocks

WESTERN BELT OF THE CORDILLERA REAL (COLLISIONAL SEQUENCE)

-  Alao-Paute greenstone and metasedimentary division
-  Peltetec subduction complex including:
- (A) Río Blanco de Patate gabbro
 - (B) Penipe ophiolitic rocks
 - (C) Oceanic sediments, turbidites, and olistostromes of the Río Paute-Jadán
 - (D) Raspas Complex: ultramafic rocks, blue and green schists
-  Undifferentiated divisions of the Western belt to the west of the Peltetec suture
-  The Alao-Paute division and the Peltetec subduction complex covered by younger rocks

CHAUCHA-ARENILLAS TERRANE

-  Generally high-grade metamorphic rocks including quartzite, amphibolite, schist, and gneiss with muscovite/biotite $\pm$ sillimanite
-  Proposed limits within the Peltetec (east) and Pallatanga-Palenque/Calacalí-Pallatanga (west) sutures covered by younger deposits

NONO-SHOBOL TERRANE (DEFINED BY MEGARD AND LEBRAT, 1986)

-  Principally basalt and andesite with low-grade metamorphic marine sediments

LA BOCANA TERRANE

-  High-grade metamorphic rocks including amphibolite, quartzite, migmatitic pelitic gneiss with garnet and para-autochthonous granite
-  Proposed southern extension toward Peru. To the east and north, the terrane is limited by the Las Aradas fault and the Baños front

OTHER UNITS

-  Ophiolitic complex of the Cordillera Occidental and its southern extension
1 = Pujilí-Saquisilí; 2 = Pallatanga; 3 = Palenque
-  Granitoid, schist, and gneiss frequently with blue quartz: tectonized rocks related to the Baños front
-  Calc-alkaline intrusives of probable Jurassic age

GEOLOGICAL SYMBOLS

- Geological contact
- Undetermined geological contact
- Suture or major thrust/drag
-  Polymetallic mines related to the Western belt of the Cordillera Real and the Baños front

2. UNDIFFERENTIATED METAMORPHIC ROCKS OF THE CORDILLERA REAL

The area that lies between the Baños front/Las Aradas fault in the west, and the sub-Andean front in the east, consists principally of metamorphic rocks. Although various important changes have been recognised within this belt we are as yet unable to subdivide it on a regional basis, and therefore it is shown as a single undifferentiated unit in Figure 1. In spite of this, it should be emphasised that this is undoubtedly a compound unit which consists of rocks of differing composition, grade of metamorphism and, probably, of different ages. The structure is complex and, in some areas, there is evidence of polyphase penetrative deformation involving horizontal tectonics.

In general, to the south of Cuenca much of the Cordillera Real is made up of a monotonous sequence of low-grade, semi-pelitic and pelitic rocks, which can be traced further south into the Loja area where it can be interpreted to overly an older (?Precambrian) higher-grade metamorphic basement complex comprising schists, gneisses, quartzites, amphibolites and migmatites. The low-grade sequence appears to be almost exclusively derived from a continental source and it has been informally named the Loja phyllitic/semi-pelite division (Litherland, 1987). Its age is unknown, but based on regional correlation with Peru, it is possibly lower Palaeozoic (see Laubacher and Megard, 1985).

To the north of Cuenca, the Loja phyllitic/semi-pelite division disappears and is replaced by pelitic schists, gneisses, quartzites, metagreywackes and metavolcanics. Traverses completed in the northern half of the Cordillera Real have confirmed the presence of serpentinite blocks in various rivers which could indicate the existence of an as yet unidentified accretionary episode. Recent work in the Llanganates area has discovered skarn sequences with a flat tectonic foliation.

The western limit of the undifferentiated belt, the Baños front (Figure 1), is provisionally interpreted as tectonic zone which defines the eastern limit of the Western Belt of the Cordillera Real. According to this hypothesis the rocks which lie to the east of the Baños front would be older than the entire Western belt's sequence. However, this hypothesis requires confirmation and the Project is now concentrating a major part of its field effort in an attempt to resolve some of the outstanding problems in this belt.

In spite of these uncertainties, however, sufficient studies have been undertaken to rule out the existence of Feininger's (1987) terrane boundary crossing the Cordillera Real from Riobamba to Sangay volcano and separating Palaeozoic metamorphic rocks to the south (in "Santiago terrane") from Cretaceous metamorphic rocks in the north. Figure 2 shows that western belt divisions can be traced across such a line.

3. THE WESTERN BELT OF THE CORDILLERA REAL

Our preliminary findings concerning the recognition of the Western belt of the Cordillera Real have already been published (Aspden et al., 1987) and further details are given in the 1986-1987 Annual Report of the Cordillera Real Geological Research Project (Litherland 1987). The regional distribution of these rocks and their postulated extension into SE Ecuador is shown in Figure 1. More recently, geological investigations, which form part of an ongoing study into the nature of the Western belt, have been completed in the area between Baños in the north and Cuenca in the south. These investigations, based largely on the detailed study of the airphotographs together with numerous field checks, have resulted in a more meaningful sub-division of the Western belt rocks into a series of informal lithological units (Figure 2) described below.

3.1 The Guasuntos, Guamote and Cebadas divisions

These crop out between the Ingapirca and Peltetec faults (Figure 2). The Guasuntos and Cebadas divisions are dominated by black slates with intercalations of dark or pale fine to medium-grained quartzites. They possibly represent the same lithostratigraphic unit but further mapping and structural studies are required to test this hypothesis.

The Guamote division is dominantly quartzitic but also contains slate/phyllite intercalations. It can be traced for 100 km from Punín in the north to the Río San Pedro (Cañar) in the south. In Figure 2 it includes the 'Ingapirca Formation', which was previously grouped with the Yunguilla Formation (INEMIN 1:100000 Cañar Sheet). North of Palmira, however, there are also pale, pink and purple quartzites with intercalations of grey, green and purple slates. This northward change to a more shallow water facies is also marked by the presence of orthoconglomerates and diagenetic concretions.

The tectonics of this belt of continentally derived metasediments is marked by upright D3 open to close folds trending ca. 70°, the same trend as the imbricate reverse faults which affects the "Macuchi" volcanics east of Guasuntos; these structures are tentatively correlated. To the north of Palmira the D3 folds are superimposed on an original subhorizontal S1 cleavage, and south of Palmira on an original subhorizontal S2 cleavage; both of which are best seen in the slate intercalations. There are some sectors where relations with S1 or S2 indicate tectonic transport westwards.

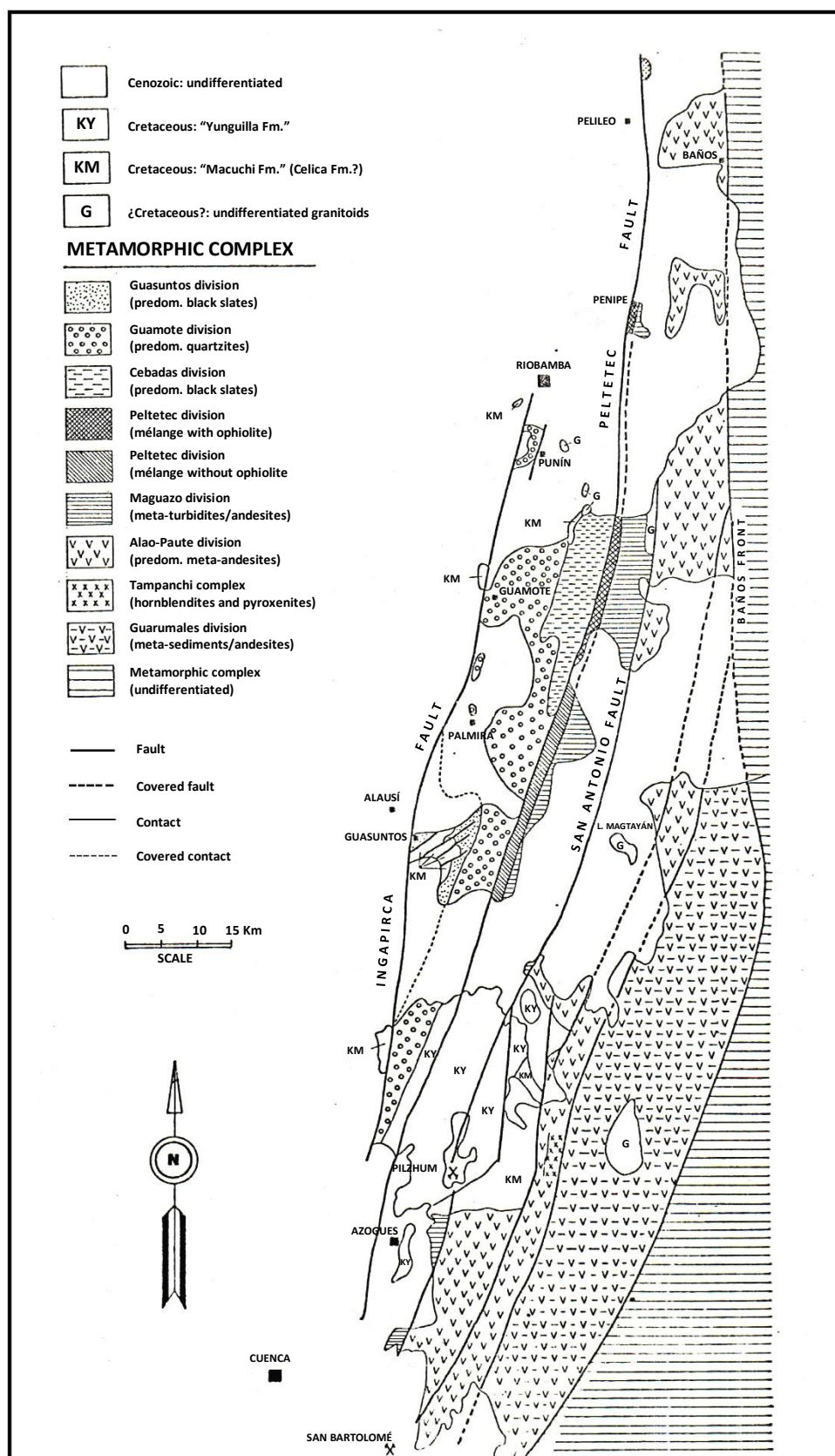


Figure 2. Geological map of the Western belt of the Cordillera Real metamorphic complex: Baños-Cuenca. Contacts with cover sequences are adapted from the INEMIN 1:100000 sheets for Azogues, Cañar, Alausí, and Riobamba

3.2 The Peltetec division

This can be traced for 100 km from the Río Blanco de Patate in the north, to the Río Zula, east of Guasuntos, in the south. The tectonic front which divides these rocks from the Cebadas/Guamote division is now manifested as a Cenozoic fault, the Peltetec fault (Figure 2), which is a clear feature on imagery. This fault is a reactivation of an older basement structure.

North of the Río Cebadas (Figure 2) the Peltetec division is a tectonic *mélange* ca. 2 km wide, which includes ophiolitic fragments: serpentinites and metamorphosed gabbros, picrites and basalts. Such rocks have been noted in the following sectors: Río Blanco de Patate, Penipe, Río Alao and Río Huarguallá. These fragments of oceanic crust are mixed with tectonic slices of oceanic-type sediments (cherts, mudstones) and, at Huarguallá, slices of blue-quartz granitoid similar to that found close to the Baños front in the east.

South of the Río Cebadas the igneous ophiolitic rocks are absent in the Peltetec division and on the Guamote-Atillo road and along the Río Zula there is a tectonic *mélange* of oceanic sediments and blue-quartz granitoids. The chert fraction is particularly prominent along the Río Zula.

Primary tectonic structures, first cleavage and tectonic movement zones in the *mélange*, are steep throughout the Peltetec division, in marked contrast to those of the ‘flat belt’ of the Guasuntos/Guamote/Cebadas division to the west.

3.3 The Maguazo division

This can be traced for 150 km from Penipe in the north to Río Paute in the south. Other traversed sectors include Río Alao, Río Huarguallá, the Guamote-Atillo road and Río Zula. The characteristic rock is a well-banded and graded fine graded quartzose turbidite, but coarse grained, poorly sorted volcanic-rich, proximal turbidites are also present. In addition, the Maguazo division includes massive meta-andesites, meta-tuffs, pale, black and red ribbon cherts, black slates, orthoquartzites, and olistolithic fine-grained, pale and dark marbles.

Although certain lithologies are found in both the Peltetec and Maguazo division the latter appears to be characterised by its turbiditic nature and the presence of massive meta-andesites. Furthermore, the Maguazo division shows an absence of tectonic *mélange* features. Indeed, by using the ‘way-up’ evidence in the turbidites, ripple cross bedding and graded bedding, coherent first phase (D1) tight-to-isoclinal, upright, synclines can be mapped in both the Río Alao and Río Paute and it is possible that this structure is continuous between the two sectors.

3.4 The Alao-Paute division

This can be traced for over 150 km from the Patate-Baños sector in the north, through upper Río Alao, Laguna Atillo to the Río Paute in the south. Lithologies are dominated by massive greenstones (meta andesites) with subordinate agglomerates, green phyllites (metatuffs), black slates, pelitic phyllites, quartzites and thin black marbles.

The rocks in the north are of slightly higher grade and more schistose being cut by a steep second penetrative cleavage (S2) whilst those of the Río Paute are only affected by a steep first cleavage.

In the Río Alao the contact between the Alao-Paute and Maguazo divisions is marked by a 300-500 m belt of undeformed pink chalcedonic rock which replaces and cuts the metamorphic rocks. Although this belt is of probable Cenozoic (?Tarqui) age it follows the older San Antonio fault which separates lower grade Maguazo division with one penetrative cleavage from higher grade Alao Paute division with two, suggesting downthrow to the east. The San Antonio fault can be tentatively traced to the Río Paute where it also separates the Maguazo and Alao-Paute divisions.

3.5 The Tampanchi mafic complex

This corresponds to a belt of “amphibolites” on the INEMIN 1:100000 Cañar Sheet. A reconnaissance traverse indicates clinopyroxenites, with cumulate textures, hornblendites and gabbros, associated with hornblende gneisses. These rocks are cut by intermediate to acid stocks and veins.

3.6 The Guarumales division

The status of this division remains tentative vis-a-vis its association with the other divisions of the Western Belt. Lithologies comprise pale green phyllites (?metatuffs), chloritoid-bearing meta-andesites, pelitic phyllites, black phyllites, quartzites, thin black marbles and calc-silicates. A steep penetrative first cleavage predominates.

3.7 Structural limits of the Western belt

In the west the outcrop limit of the Western belt is defined by the Ingapirca fault. The eastern limit of the Western belt is more difficult to define but we believe that it corresponds to the Baños front, which was first recognised in the area ca. 1 km east of Baños, where low-grade rocks belonging to the Alao-Paute division are juxtaposed against higher-grade, garnet-bearing schists, gneisses and amphibolites to the east. Subsequent fieldwork has confirmed the regional importance of this line but further studies will be necessary in order to obtain a more complete understanding of its precise nature.

To the east of Sigsig for example (Figure 1), movements associated with the Baños front have produced a ca. 6 km wide zone of highly tectonised rocks which contain a high percentage of mylonites derived from a variety of protoliths. Structural dips throughout the entire belt are consistently to the west and vary from moderate to steep. In the west the zone includes a ca. 1 km belt of mylonites, tectonised greenstones and minor metasediments of the Alao-Paute division. Further to the east, however, a ca. 2-3 km wide, generally schistose sequence of pale-green rocks are exposed. This sequence is in part chloritoid-bearing and consists principally of metalavas, metatuffs and tuffaceous metasediments which have tentatively been assigned to the Guarumales division.

As one crosses the Baños front, Western Belt lithologies disappear abruptly. To the east they are replaced by yet another 3-4 km belt of mylonites which consist mainly of quartzose/quartz-feldspathic schists and gneisses many of which contain quartz-feldspathic augens. Large megacrysts (3-4 cm) of K-feldspar are common and a characteristic feature of these mylonites is that they frequently carry grains of pale, bright-blue quartz. Although blue-quartz has been found in isolated outcrops of garnet-bearing schists, which may suggest a sedimentary protolith, the majority of these rocks are demonstrably derived from igneous rocks. Around Peggy Mine for example (Figure 1), a relatively undeformed plutonic lens is preserved which, with increasing deformation, can be traced into mylonitic gneisses and schists both to the east and west.

Such plutonic rocks have now been recognised at several places along the Baños front (Figure 1) and in their undeformed state they are very distinctive. They vary from medium to coarse grained and often contain blue-quartz. In addition, they carry large, randomly orientated, late-stage, megacrysts of K-feldspar which when fresh have a greasy lustre and are greyish-blue to smoky-brown in colour. In the Tres Lagunas Pluton, to the east of Saraguro (Figure 1), megacrysts up to 14 cm in length have been observed and these contain the corroded remnants of earlier formed crystals of cream-coloured plagioclase and biotite. Although minor amounts of muscovite have been seen in thin sections, biotite, which is often somewhat chloritised, represents the major mafic phase. Both sedimentary and igneous xenoliths are present: the former of which may carry tourmaline. No chemical analyses are available for these rocks but they appear to have a restricted compositional range with model analyses varying between granodiorite and granite.

The presence of detrital blue-quartz in the Guamote division quartzites and of minor amounts of blue quartz-bearing rocks, that also contains megacrysts of smoky alkaline-feldspar, within the Peltetec division, suggests that these plutons pre-date the entire Western belt sequence.

In order to further understand the pre-Western Belt history of the Cordillera Real it will be necessary to study these 'blue-quartz' granitoids in more detail and to establish their precise relationship with those metamorphic rocks which lie to the east of the Baños front.

3.8 Younger Cretaceous Units

Figure 2 shows a revision of outcrop distribution of the Cretaceous 'Macuchi' and Yunguilla Formations. In this area we suspect that rocks previously mapped as 'Macuchi' Formation (INEMIN 1:100000 Cañar, Alausí and Riobamba Sheets), in fact belong to the Celica Formation (see also Lebrat et al., 1986) and they are found on both sides of the Ingapirca fault along which they are downthrow to the west against the metamorphic basement. Near Guasuntos, the Guasuntos division is thrust over the 'Celica' along a series of imbricate reverse faults whilst further south a large sector of rocks previously regarded as part of the metamorphic "Paute Group" (Baldock, 1982) is reinterpreted as 'Celica' lavas which must lie close to the base of the Yunguilla Formation. It is clear that the 'Celica'/Yunguilla sequence is not unmetamorphosed Western belt rocks (cf. Bristow, 1973; INEMIN 1:100000 Cañar Sheet) since, regionally, both these formations overlie the Western belt divisions (Figure 2).

Small undeformed, granitoid/hornblendite bodies cut the western belt sequence (Figure 2). These intrusives show radiometric ages at Amaluza and Magtayán ranging from 40 to 85 Ma (Kennerley, 1930; Baldock, 1982). At the junction of the Cebadas and Alao rivers one such pluton is intimately related to a newly-discovered outcrop of 'Celica' volcanics.

3.9 Interpretation of the Western belt of the Cordillera Real

The Western belt as shown on Figure 2 shows lithological divisions with tectonic contacts which can be traced for considerable distances and which may also exhibit individual tectono-metamorphic characteristics. Whilst any interpretation must, at this stage, be regarded as preliminary, we propose the following model as a working hypothesis:

- (a) The Peltetec Fault is a rejuvenated suture and the Peltetec division represents a subduction complex.
- (b) The Maguazo division is a fore-arc sequence.
- (c) The Alao-Paute and Guarumales divisions are the remains of volcanic arc/back arc sequences tectonically emplaced along the Baños front.

We assume that the 'Alao Paute arc' was produced as a result of the eastward subduction of oceanic lithosphere along the Peltetec line and suggest that perhaps the Tampanchi complex represents a deeper magmatic level within the arc. Continued subduction ultimately led to the destruction of the oceanic crust and the emplacement of the Chaucha-Arenillas block (see below). The approach and subsequent emplacement of the Chaucha-Arenillas terrane would also provide the principal continental source for the molasse-type sediments of the Guamote quartzite division which were then thrust over the Chaucha-Arenillas block to the west.

Structural information of the Western belt is at present insufficient to permit a detailed interpretation. However, the sudden change from subhorizontal to vertical structures as one passes from west to east across the Peltetec suture could suggest an 'imbricate model', such are associated with, continent-continent collision zones (e.g. Sudgen, 1987). Indeed, it could be argued that the preservation of discrete lithological divisions over 150 km of strike favours right-angled rather than oblique collision. The consistent, albeit rather steep, westerly dips recorded throughout the belt of mylonitic rocks near Sigsig could be interpreted as an imbricate series of high-angle, back-arc thrusts which were generated during the accretion of the Western belt onto a pre-existing metamorphic basement, represented by those rocks that are now exposed to the east of the Baños front.

3.10 Extension of the Western belt through Ecuador

North of Patate, the Western belt metamorphic rocks are buried within the Inter-Andean Graben and are only exposed near the Colombian border around Ambuquí in the form of greenstones and cherty quartzites and black slates (Litherland, 1987). / Serpentinite blocks have also been reported from this area (M. Hall, personal communications).

To the south of Sigsig the Western belt disappears under a thick cover of younger deposits but traverses carried out in the Loja and Saraguro areas indicate that western belt rocks are not present in the southern part of the Cordillera Real. Hence one is forced to conclude either that these rocks disappear somewhere between Sigsig and Loja, possibly along the Las Aradas Fault, or alternatively, that they swing abruptly to the west, and if so, their correlatives should be found in SW Ecuador.

At present we favour this latter possibility and suggest that the Raspas complex of El Oro Province, which consists of a mixture of ultramafic rocks, blueschists, greenschists, quartz sericite/muscovite schists and quartzites, represent the continuation of the Western belt. On a recent visit to El Oro, it was clearly demonstrated that the greenschists of the southern margin of the Raspas complex are separated from amphibolites and migmatites to the south by a 1-2 km wide zone of mylonites (Aspden and Litherland, 1987). This zone, which tectonically defines the southern limit of the Raspas package, has not been previously recognised but it is of obvious fundamental importance since it clearly marks the break between subduction zone- related rocks (i.e. the blueschists of Raspas) and an older continental (i.e. migmatitic) basement to the south.

This interpretation, however, is in direct contradiction to that of Feininger (1978) who concluded that the greenschists, quartzites and mica schists (i.e. the pCpq, pCpqs, divisions of the Piedras Group) were of Precambrian age and therefore unrelated to the blueschists of the Raspas Formation which have a K/Ar age of 132 Ma (Feininger, 1980). The main evidence for Feininger's interpretation comes from the fact that he correlated the greenschists which lie to the north of the mylonite zone, with a belt of amphibolites that are exposed immediately to the south (i.e. the pCpa division of the Piedras 'Group'), and from which a single K/Ar date of 743 ± 14 Ma has been obtained (Baldock, 1982). In our view these amphibolites (i.e. pCpa) are distinctive, both in aspect and structure, and should be clearly distinguished from those rocks which lie to the north. Those rocks which we would include within the Raspas package (i.e. the pCps and pCpq of the 'Piedras Group', Feininger, 1978) show a common, generally steep, penetrative second (S2) cleavage which is also present in the Raspas blueschists. This field observation alone strongly suggests that these rocks have a similar tectonic history and are therefore likely to be of a similar age. On the other hand, the amphibolites and gabbros, which lie to the south of the mylonite zone (i.e. the pCpa division of the 'Piedras Group') we would consider to represent an integral part of the older (probably Precambrian) La Bocana terrane (see below).

The northern limit of the Raspas complex is defined by the La Palma fault (Feininger, 1978) which we tentatively suggest to represent the continuation of the Peltetec suture. The evidence for the La Palma fault being a suture is that it juxtaposes the generally higher- grade metamorphic rocks of Chaucha-Arenillas terrane (see below) which are essentially continental in origin against the oceanic rocks of the Raspas complex. In SW Ecuador equivalents of the Cebadas, Guasuntos and Guamote divisions are apparently not preserved to the north of the La Palma fault, and we would correlate the entire Raspas package as being equivalent to those divisions of the Western Belt which lie to the east of the Peltetec suture (Figure 1).

4. THE CHAUCHA-ARENILLAS TERRANE

Due to the extensive cover, particularly of younger volcanics, the precise limits of the Chaucha-Arenillas terrane are uncertain. However, we would suggest that it is bounded in the east by the Peltetec suture and most probably in the west by the Pallatanga-Palenque/Calacalí-Pallatanga sutures (Figure 1).

Evidence presented elsewhere has already argued that the limit of the allochthonous Cordillera Occidental is marked by the Calacalí-Pallatanga ophiolite line (Lebrat et al., 1986, Aspden et al., 1987). Lebrat et al. (1986) believe that this line can be extended southwards from Pallatanga, where it passes immediately to the west of Chaucha (see also Megard and Lebrat, 1986). We propose that it then swings southwards through the Palenque ophiolite complex (Figure 1).

Although serpentinites were previously known from Palenque area (INEMIN 1:100000 Santa Rosa sheet), reconnaissance studies have confirmed the existence of a fairly complete ophiolite sequence which consists not only of serpentinitised ultramafics but also pegmatitic gabbros, pillow lavas, basalts and pelagic sediments (cherts and black phyllites). Included within the complex, either in *mélange* zones or possibly as tectonic slices, are high-grade xenolithic sillimanite-bearing orthogneisses and hornblende gneisses.

Traverses carried immediately to the south and to the east of the Palenque ophiolite complex indicate the presence of a variety of metamorphic rocks comprising mainly continental quartzites and gneisses, some of which sillimanite-bearing. Further south, immediately to the north of the Raspas complex, near Arenillas, amphibolites are present associated with a belt of semi-pelitic gneisses.

In contrast, to the north of the Palenque ophiolitic complex, and partially exposed along the road which follows the Jubones river to the east of Pasaje, is a sequence of low-grade, black phyllites and slates which in the east contain minor cherts and are associated with basalts and diabases. Towards the west these rocks become increasingly feldspathic and pale sericitic phyllites are dominant.

To the east of Chiche, exposures along the main Pasaje road are generally poor but quartzites and gneisses, identical to those seen to the south of the Palenque ophiolite complex, are present. Although previously all the metamorphic rocks that are exposed along the Jubones road were considered to be of the same age and belong to the 'Tahuín Series' (INEMIN 1:100000; Machala sheet) we would dispute this interpretation and argue that there are clearly two sequences of different ages. The eastern sequence is essentially continental and consists of high-grade gneisses and quartzites whereas the western one is comprised of low-grade marine/pelagic sediments and volcanics. The presence of the Palenque ophiolite complex between these two sequences also supports such an interpretation and indeed suggests that the boundary between these two sequences is of probable regional significance.

In the majority of publications dealing with Ecuador the E-W striking Jubones fault is considered to be of fundamental importance. For example, Feininger (1987) divides his Biron terrane, from his Chaucha terrane to the north along it (see also Megard and Lebrat, 1986). In our interpretation however, we do not interpret the Jubones fault to be a suture and consider that movements along this zone are probable younger and were mainly in the vertical sense (see also Baldock, 1982). According to our model, equivalent rocks should be found on both sides of the Jubones fault east of Chiche and we regard recent work, carried out by the Belgium (geological) Mission, in conjunction with INEMIN, as providing the critical evidence to support this contention. Geological mapping around the Chaucha Area (INEMIN-Misión Belga, 1986) has confirmed the presence of basement inliers consisting of mica schists, some of which contain andalusite and sillimanite (fibrolite), and also of andalusite-bearing, quartz-feldspathic gneisses and amphibolites. Further to the south (INEMIN 1:100000; Girón Sheet), a single basement inlier consisting of quartzite and biotite schists has also been mapped. These rocks are shown collectively as the Chaucha basement in Figure 1 and we would suggest that together they represent the continuation northwards across the Jubones fault of the 'Arenillas' basement. The existence of a small inlier of biotite muscovite granitic gneiss in the area of Manú, to the west of Saraguro (Figure 1), has also been confirmed. In hand specimen these rocks are very similar to those which occur in Chaucha (M. Merlyn, personal communications) and they probably mark the approximate eastern limit of the proposed Arenillas-Chaucha terrane in southern Ecuador.

Further to the north outcrops of medium and high-grade metamorphic rocks are unknown to the west of the Peltetec line. However recent descriptions of cordierite gneiss xenoliths in Plio-Pleistocene lavas from the Quito area (Bruet, 1987) suggest that the Arenillas-Chaucha terrane may continue northwards until this latitude, albeit in a possibly attenuated form.

5. THE NONO-SHOBOL TERRANE

The Cordillera Occidental of Ecuador was previously considered to be made up of a single formation, the Macuchi Formation, which ranged from upper Cretaceous to Eocene in age and was composed principally of volcanic sandstones, re-sedimented turbiditic tuffs and andesite to basaltic-andesite lavas (Henderson, 1979, 1981). More recently Megard and Lebrat (1986) have suggested that the Cordillera Occidental consists of two different, probably allochthonous, volcanic-arc sequences. The older one, of upper Cretaceous age, they named the Nono-Shobol, whereas the younger Eocene sequence they referred to as the Macuchi arc.

As shown in Figure 1 the northern part of the Cordillera Occidental is undifferentiated but to the south of Pallatanga we follow Megard and Lebrat (1986) and the volcano-sedimentary sequence to the west of the Pallatanga-Palenque suture is considered to be part of Nono-Shobol terrane. As discussed earlier, we do not consider that the Pallatanga-Palenque suture is terminated by the Jubones fault but rather that it continues to the south and exits through the Palenque ophiolitic complex. Hence the sequence of phyllites, slates and basaltic rocks exposed along the western part of the Jubones river would therefore represent the southern continuation of the Nono-Shobol terrane.

6. THE LA BOCANA TERRANE

Only the northern part of this block has been examined on our field reconnaissance, but, as stated earlier, we interpret the tectonic limit between the La Bocana terrane and the Raspas complex to the north to be represented by a zone of previously unrecognised E-W striking mylonites, good exposures of which can be seen to the south of the road bridge over the Río Naranjo on the El Playón-Balsas highway. The eastern margin of this block is defined by the Las Aradas fault where the generally E-W structural grain of southwest Ecuador terminates abruptly and is replaced by N-S striking metamorphic rocks of the southern Cordillera Real. Cropping out along the northern margin of the La Bocana terrane is a belt of amphibolites and amphibolitic gneisses which, in the Portovelo area to the east, have given a K/Ar age of 743 ± 14 Ma (Kennerley, 1980). Although previously these rocks were correlated with the Las Piedras 'Group' (pCpa) to the north (Feininger, 1978), we suggest that they are an integral part of the La Bocana terrane. These amphibolites pass southwards into incipiently migmatised, garnetiferous, pelitic gneisses; and in small town of La Bocana (Figure 1) after which this terrane is named, the sequence consists of migmatitic, banded-gneisses and deformed para-autochthonous granites.

According to Feininger (1978, 1982) these latter rocks, belong to the 'Tahuín Group' which he traces southwards into virtually unmetamorphosed, fossiliferous, Palaeozoic sediments. As pointed out by Baldock (1982) however, it is probable that Feininger's original 'Tahuín Group' contains units of significantly different ages and a much more plausible interpretation would be that the higher-grade gneisses and schists described above, i.e. the San Roque 'Formation' (Baldock, 1982) in fact represent an older basement, whereas the lower grade phyllites and quartzites to the south, i.e. the Capiro 'Formation' are a Palaeozoic cover sequence.

Although the Capiro 'Formation' to the south of the Raspas complex was not visited by us, southwards of Portovelo (INEMIN 1:100000 Zaruma sheet) the amphibolites of the La Bocana terrane pass into quartzites and semi-pelitic gneisses, of the San Roque 'Formation'. Near to Porotillo however, there is an abrupt change and these high-grade rocks suddenly disappear to be replaced by low-grade slates and phyllites of the Capiro 'Formation'. These observations suggest a basement/cover relationship and do not support the idea of a transitional contact between the Capiro and San Roque 'Formations'.

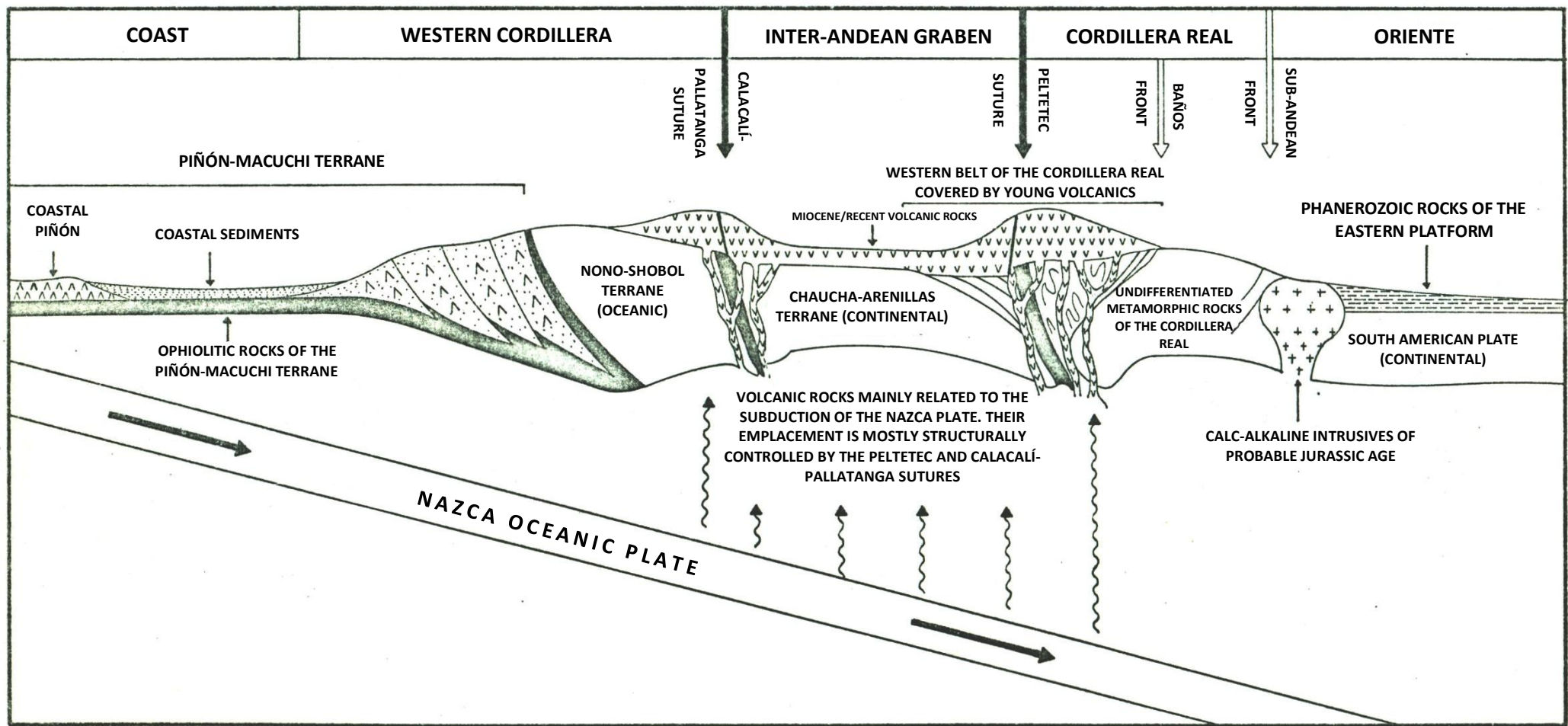


Figure 3. Schematic West-East cross-section indicating the main tectonic elements of Ecuadorian geology, north of Guayaquil. The Piñón-Macuchi and Nono-Shobol terranes are from Megard and Lebrat (1986), and the Chaucha-Arenillas terrane is by the present publication. The Baños front is interpreted as a continental margin.

The proposed southern extension of these rocks into Peru shown in Figure 1 is purely speculative but it is of interest to note that many of the rock-types represented in San Roque 'Formation' (and also in the Arenillas-Chaucha terrane to the north) have also been described from the Arequipa massif of coastal Perú (Shackleton et al., 1979).

7. POST-COLLISION HISTORY

Although the precise age of the Western Belt remains uncertain, as discussed earlier, we regard the entire sequence and also the timing of the collision of the Chaucha-Arenillas block along the Peltetec suture, to pre-date both the Celica and Yunguilla Formations. The occurrence of later cross-cutting plutons in the Western Belt one of which (the Magtayán/Atillo pluton) has given a radiometric date of 85 ± 3 Ma (Baldock, 1982) would also support this contention. Following the accretion of the Chaucha-Arenillas block the Nono-Shobol and Macuchi-Piñón terrane were emplaced and these events probably took place during the latest Cretaceous and the Eocene respectively (Megard and Lebrat, 1986).

Having briefly mentioned the major collisional episodes we would now like to comment on certain aspects of Ecuador's post-accretionary history and within the context of the terrane model presented here, to demonstrate the profound influence that collision related structures have exerted on subsequent geological evolution (Figure 3).

In particular we suggest that the Inter-Andean graben is structurally controlled by the reactivated Calacalí-Pallatanga suture in the west and by the Peltetec suture in the east. Furthermore, the presence of these two sub-parallel regional zones of crustal weakness not only accounts for the vast amounts of post-Eocene (dominantly Plio-Pleistocene) volcanic detritus within and along the flanks of the Inter-Andean graben but also neatly explains the presence of the double line of young volcanics along its eastern and western margins to the north of Guayaquil (Figure 3).

As direct evidence to demonstrate the importance of these older collisional structures and their subsequent reactivation the Peltetec Fault between Pelileo and Cuenca (Figure 2) provides a convincing example. In this sector the fault, which is clearly the reactivated Peltetec suture, can be seen as a strong lineament on the imagery and along the Río Chambo ophiolitic rocks of the Peltetec division are faulted against Pliocene lavas which are downthrown to the west. Further to the south the Peltetec fault cuts both the Pleistocene Tarqui and the Cretaceous Yunguilla Formations and we would speculate that this line was an important structural control which influenced the development of the Miocene Cuenca basin.

8. LOCATION OF POLYMETALLIC MINERAL DEPOSITS IN THE CORDILLERA REAL

The presence of various polymetallic mineral deposits in the Cordillera Real is well-known and the exploitation of many of these dates from pre-Spanish times. Although we have not as yet carried a systematic study of these deposits they all appear to have a similar metallogeny (i.e. Fe + Cu + Pb + Zn $\pm$ Au) but until now they have been regarded as isolated mineral occurrences rather than representing members of a single metallogenic province.

All the known major (i.e. those which have been mined in one form or another) polymetallic occurrences in the Cordillera Real are shown in Figure 1 and as can be seen they are spatially closely associated with the Alao-Paute and Guarumales divisions of the Western Belt which lie to the east of the Peltetec suture. In fact, with the exception of Pilzhum, which lies along the San Antonio fault and is hosted by the Tarqui Formation, all the mines are located either astride or at most few kilometres from the Baños front.

Our projected extension of the Baños front into SW Ecuador would also include the mines of Portovelo and Fierro Urcu as representing the southern limit of this same metallogenic province.

Areas of unknown mineralization are often strongly silicified and invariably are associated with young volcanics, in particular in the north with the Altar volcanics and in the south (around Sigsig) with the Tarqui Formation. Interestingly however the mineralization is not confined to a specific host but may occur in a variety of rock types. In Peggy Mine for example (Figure 1) which lies ca. 1/2 km to the east of the Baños front the main mineralisation appears to be located within late cross-cutting fractures in 'basement' blue-quartz granitoids but close by extensive workings are also present in a breccia pipe of the Tarqui Formation. Further to the west at San Bartolomé, mineralization occurs within dark green metavolcanics of the Alao-Paute division.

The interpretation of the polymetallic mineralisation in the Western Cordillera must await the results of follow-up studies which are planned for the future. However, the close spatial relationship between these deposits and the Baños front clearly establishes the importance of this older collision-related zone as an area of considerable economic interest. As is the case with the Peltetec suture to the west, it appears that many of the numerous faults and shear-zones which are associated with the Baños front have been reactivated during the Cenozoic. These faults would then provide a ready-made and extensive system of channel-ways, in particular, for the circulation of fluids associated with the Plio-Pleistocene volcanics. The scavenging of metals from deeper levels and their re-deposition near surface is probably the single most important process to account for the presence of the various polymetallic deposits along the Baños front (Figure 3).

9. CONCLUSIONS

We hope that the ideas expressed in this paper will stimulate a considerable amount of discussion amongst those people who are truly interested in unravelling the complexities of Ecuadorian geology. The model presented requires further testing before it becomes a basis of fact however we hope that we have demonstrated the value of such models in that, apart of their predictive value they also enable one to appreciate the significance of many elements of the geology within a more meaningful regional context.

Obviously various questions remain to be answered but in particular the “undifferentiated” metamorphic rocks of the Cordillera Real (Figure 1) hold many secrets. The understanding of this belt, its relation to the Baños front in the west and the Tertiary sub-Andean front in the east, and its setting as an important primary source of gold is now the principal objective of the Cordillera Real Project.

ACKNOWLEDGEMENTS

The INEMIN counterparts, Engineers Ramiro Bermúdez and Francisco Viteri, who work with the Cordillera Real Project, assisted us in the field; Prof. Pablo Duque showed us the metamorphic province of El Oro.

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APPENDIX 9

Commission Report of the El Oro Province



INEMIN

INSTITUTO ECUATORIANO DE MINERÍA
CORDILLERA REAL GEOLOGICAL RESEARCH PROJECT

No. 3810

QUITO, JULY 28, 1987

TO : GERENTE TÉCNICO

FROM : DR. JOHN ASPDEN, DR. MARTIN LITHERLAND
CORDILLERA REAL PROJECT

SUBJECT : Technical Report of the commission to El Oro, carried out from
July 6 to 13, 1987

INTRODUCTION

This trip was organized to demonstrate the nature of the “Western Collision Belt” of the Cordillera Real, south of the Alao-Baños area. Additionally, the primary metamorphic lithological types that make up the Cordillera Real south of Cuenca were examined.

Based on field evidence, the possibility of correlating the metamorphic rocks of the Cordillera Real with the rocks exposed in the southwestern sector of Ecuador was examined.

ASSIGNED PERSONNEL

The following individuals participated on behalf of INEMIN:

Edgar Salazar
Martin Litherland
John Aspden
Ramiro Bermúdez
Francisco Viteri

On behalf of the Politécnica Nacional, the participant was: Pablo Duque

The results obtained are summarized below:

JULY 6

The group flew from Quito (07:00 am) to Cuenca (07:40 am), where they were met by INEMIN drivers with the vehicles. They departed directly for the field.

(a) Visit to Asunción Dudas (Cañar Sheet 557/125) to examine the contact relationships between the 'Paute Series' and the Yunguilla Formation

Bristow (1973, p. 11) originally described this contact and interpreted it as demonstrating a gradual transition to the west from the metamorphic rocks of the 'Paute Series' into the non-metamorphic sediments of the Yunguilla Formation. Bristow's interpretation has subsequently been cited in publications related to Ecuadorian geology (e.g., Baldock, 1982), and the Maastrichtian-age fossils found in the Yunguilla (Bristow, 1973) have been used as evidence to support the position that at least part of the 'Paute Series' would be of a similar age.

The work carried out by the Cordillera Real Project indicates that the metavolcanic and metasedimentary rocks of the 'Paute Series' could be traced to the north - albeit discontinuously - along a strike, and that they outcrop in several places on the western slopes of the Cordillera Real. In particular, these rocks that outcrop in the Paute area, east of Cuenca, could be correlated with a similar sequence of greenschists and metasediments exposed in the Alao Valley (Riobamba Sheet) and also with those between Baños and Patate (Baños Sheet) (See First Annual Report, Cordillera Real Project, 1987). This rock belt has been informally named as the Alao-Paute greenstone and metasedimentary division and is associated in some places with partially preserved ophiolitic sequences (Aspden et al., 1987). The presence of these latter rocks suggests that the entire Alao-Paute belt could be related to a collision, and this gives rise to the need to indicate an age for said event to understand the geological evolution of the Cordillera.

Thus, in view of the potential importance of the Asunción Dudas contact, it was decided that the group should visit it so that the validity of Bristow's interpretation could be established.

The geology along the Asunción Dudas road north of Taday could be summarized as follows: exposures are generally poor, but to the east they consist mostly of massive, apparently undeformed volcanics of the 'Paute Series'. Approximately 50-100 m before Asunción Dudas, there is a small outcropping of altered phyllitic rocks containing several minor D2 folds with an approximate N-S strike and gentle dips. No further outcrops were found until reaching Asunción Dudas, where a fault zone is exposed.



To the east of this fault, phyllitic rocks are found and are in contact with very acidic volcanic/sub-volcanic rocks of a presumably older age (Tarqui?) to the west. Continuing west along the road, and after crossing a small tributary of the Río Dudas on the right-hand side, there are exposures of phyllites/slates with a steep dip, an approximate N-S strike, well-stratified but strongly cleaved; however, these are replaced by outcrops of a gently folded, weakly cleaved turbiditic sequence.

It must be emphasized that the rock outcrops, especially east of Asunción Dudas, are not continuous, and as a result, there is a considerable amount of discussion among the group members regarding the interpretation of the geological evidence. Edgar Salazar and John Aspden thought that the description of this contact as “transitional” was not justified based on field evidence; they suggested that, in reality, the major change from the volcanic rocks of the Paute Series to the sediments of the Yunguilla Formation could also be interpreted as abrupt. This change could, for example, be due to a major fault, of which a branch is exposed in Asunción Dudas and to the cleavage, which appears to be confined to a relatively narrow zone within the finer-grained sediments of the Yunguilla Formation immediately west of Asunción Dudas, could be associated with local tectonism along that fault. Regardless of individual viewpoints, the entire group agreed that this section did not provide sufficient evidence on which to base a positive conclusion; as such, it was not acceptable to cite Maastrichtian ages for the ‘Paute Series’ based on fossils found in the Yunguilla Formation.

(b) In the afternoon, the group visited the Paute Gorge (Azogues Sheet, 78° 50’/2° 50’) to examine the metavolcanics and metasediments of the Alao-Paute division, which are well-exposed in this area

Despite the little time remaining, an interesting sequence of volcanoclastic turbidites was found north of the main road in a small tributary of the Paute River on the right, approximately 1 km from its confluence with the Jadán River. This sequence represents one of the metasedimentary intercalations within a more massive metavolcanic and greenschist unit of the Alao-Paute division. Sedimentary structures and cleavage deviations due to lithological changes within these rocks are quite well-exposed along the riverbed. Martin Litherland was convinced that the sedimentary structures indicate a normal sequence.

JULY 7

(a) Metavolcanics and greenschists of the Alao-Paute Division

Metavolcanics and greenschists exposed along the main road north of Gualaceo (Azogues Sheet) were examined to familiarize the group with the southern continuation of the Alao-Paute division. It was noted that the metavolcanic rocks were selectively deformed, and in some of the more massive units, it was difficult to see a cleavage in hand samples. In contrast, a well-developed cleavage was clearly visible in other sectors. Agglomerates are common in this sequence, and some outcrops exhibit good tectonic lineation and elongated volcanic clasts. Trans-cordillera strikes were noted in some sectors, suggesting either a change in cleavage or a possible rotation of the blocks.

(b) Sigsig-Peggy Mine area

The group headed south toward the town of Sigsig to examine the nature of the eastern margin of the Alao-Paute division. This margin has been mapped to the north, particularly in the Baños area, where a marked change exists in both lithology and metamorphic grade as one cross from the low-grade greenstones/metasediments of the Alao-Paute division to the east, to the garnet-bearing gneisses to the west (see First Annual Report, Cordillera Real Project, 1987). The line along this change is called the Baños Front, and the visit to the Sigsig area was to demonstrate its presence in the southern sector of the country.

Immediately south of Sigsig, tectonized “protomylonitic” greenstones of the Alao-Paute division are exposed. To the south, along the eastern bank of the Santa Bárbara River on the road leading to the Peggy Mine, these rocks, which are well-exposed, become increasingly mylonitized. The strikes are around 40° and the dips are steep. The mylonitic fabric is demonstrably S2, which in other locations outside of this tectonic zone is only weakly developed in the Alao-Paute rocks.

Continuing toward the Peggy Mine, shortly after the road leading to Dacte (Sigsig topographic map, scale 1:50000, 470-620), there is a small outcrop of greenschists that is relatively undeformed; the group agreed that this could be lithologically and metamorphically assigned to the Alao-Paute division. After this outcrop, following a couple of hundred meters, the next outcrops, although superficially similar, are actually higher-grade schistose rocks in which garnet was tentatively identified.

After spending some time at this location, the group agreed that these rocks were not only of a higher metamorphic grade but also compositionally different compared to those found in the Alao-Paute division. The general consensus reached was that this section crosses a major tectonic line which likely corresponds to the Baños Front.



Then the group proceeded to the Peggy Mine, where blocks of massive granite with blue quartz were found in the Santa Bárbara River. Unfortunately, it was impossible to cross the bridge leading to the main tunnel of the mine on the western side, but the observations made suggest that the polymetallic mineralization at this point is hosted in sheared blue-quartz granites, of which massive outcrops can be seen in the lower parts of the western side. It was also emphasized that elsewhere north of the Baños Front, it is found associated with both polymetallic mineralization and blue-quartz granitoids (see First Annual Report, Cordillera Real Project, 1987).

(c) In the afternoon, the thick sequence of semipelitic rocks, which forms a major component of the southern part of the Cordillera Real, was examined along the Gualaceo-Plan de Milagro road

This belt has been informally named the Loja semipelitic division and in this area, it is separated from the Alao-Paute division by a poorly defined thin belt of older, higher-grade rocks that correspond to those found east of the Baños Front during the Sigsig-Mina Peggy traverse. Along the western margin of the semipelitic division, both S1 and S2 cleavages are present and form a conspicuous flat belt, which could be related to 'nappes'. Later, more detailed field checks should be carried out in the area to confirm this possibility. On the way back to Gualaceo, the poorly exposed rock belt between the semipelites and the Alao-Paute rocks was examined. It was found that one exposure contained blue quartz and, in thin section, these rocks also contained garnet. The group was pleased with the suggestion that these rocks, despite being reduced in width, could be better correlated with the outcrops seen in the morning on the Sigsig traverse west of the Baños Front.

Continuing west, a short stop was made near the bridge crossing the San Francisco River (Azogues Sheet, 78° 41'/2° 58') where the first recognizable greenschists of the Alao-Paute division are exposed in road cuts.

JULY 8

**Cuenca-Machala Trip,
examining exposures along the Jubones fault zone**

The outcrops exposed along the main road, between Uzhcurrumi to the east and Pasaje to the west (Machala Sheet), were examined to familiarize the group with the geology and structure of the area around the Jubones fault. The main points of interest are:

(a) The following were examined: an undeformed porphyry intrusion immediately east of Uzhcurrumi and a more basic dioritic to tonalitic body to the west. It was suggested that the latter intrusion could be a possible dating point since the outcrops were fresh and non-tectonized. A reliable radiometric age on this pluton could provide a minimum age for the major movement along the Jubones fault zone. The small river that drains the western margin of this intrusion contained gneiss blocks with biotite and sillimanite in the boulders (float).

(b) Between Chiche and Limón (Machala Sheet, 79° 38'/3° 19') the main road crosses a small river where exposed outcrops of tectonized quartzites and argillites are found. These rocks are vertical and have an E-W strike. Numerous microfractures were observed in the more quartz-rich horizons, and in some cases, these were associated with the development of small amounts of biotite. These rocks, which are considered to be of protomylonitic origin, clearly demonstrate the regional E-W strikes that characterize southwestern Ecuador, which contrast strongly with the generalized N-S strikes of the Cordillera Real itself.

(c) At 79° 39'/3° 19' strongly tectonized and epidotized volcanics (diabases) outcrop, which have been assigned to the Macuchi Formation.

Recent studies carried out elsewhere in Ecuador indicate the possibility that the Macuchi Formation may be composed of two different and probably unrelated units. The older unit consists predominantly of more basic tholeiitic basalts and is thought to be of Late Cretaceous age, while the younger unit is composed mainly of andesitic volcanics and is of probable Palaeocene-Eocene age. If this division is proven correct, then the basic composition of the lavas examined would suggest that they belong to an older tholeiitic unit.

(d) West of 79° 40' the quality of the outcrop improves in general, and several stops were made. The rocks in this area consist of a sequence of phyllites and slates with an E-W strike, generally with a steep dip. To the west, these become more feldspathic, but to the east, they are generally black or green in colour. Minor quartzites are also present, as well as volcanic rocks and cherts at the eastern end.



JULY 9 – 11

The El Oro Metamorphic Province

Baldock's (1982) summary of the El Oro Metamorphic Province is primarily derived from Feininger and his map published at a scale of 1:50000 (Feininger, 1978). Feininger proposed the following units:

- (a) Tahuín Group (Palaeozoic): north and south of the Raspas Complex. Baldock (1982) subdivided this unit into the San Roque (gneissic) and Capiro (lower grade) Formations.
- (b) Piedras Group (Precambrian): consisting of amphibolites, greenschists, quartzites, and pelitic schists.
- (c) The El Toro harzburgite and the Raspas Formation (blueschists) of Cretaceous age.

During the current commission, the group identified four geo-tectonic units in the following manner:

- (a) The Palenque ophiolitic complex: previously unrecognized, within the rocks of the northern sector of the "Tahuín Group".
- (b) The Arenillas block: a block of continental origin between the Palenque and Raspas subduction complexes.
- (c) The Raspas blueschist complex: including the entirety of the "Piedras Group".
- (d) The La Bocana block: the stable cratonic block, south of the Raspas complex.

The Palenque Ophiolitic Complex

Despite the fact that the presence of serpentinite in the Palenque River area (Santa Rosa Sheet) south of Pasaje was previously known, the group on this commission was able to confirm that this only represents part of a more extensive ophiolitic complex.

Along the Jubones road, the rocks comprise (see also July 8, point c) basaltic metalavas (greenstones), black slates, black cherts, black quartzites with cherts, grey and green banded meta-argillites, sericitic phyllites, (meta-acidic lavas?), and pale sericitic phyllites. The first penetrative cleavage has an approximate E-W strike and is associated with minor initial folds with a steep plunge, one of which, based on evidence from graded bedding, faces east. A small magnetite-manganese vein was observed. These rocks are interpreted as belonging to the same tectonic package, which includes the Palenque ophiolitic complex. Together, these rocks could form the remains of an older collision complex.

To the south, along the Palenque River, the serpentinite borders are associated, initially with cherts and black phyllites, and toward the south with basalts and cherts, pillow lavas, and tectonic mélanges. Within this tectonic sequence, there is a block of xenolithic sillimanite, containing orthogneiss and hornblende gneiss, and similar gneissic rocks; some blocks containing sillimanite were observed as boulders in the river derived from the northern Arenillas block. Undeformed microdiorite blocks were also observed.

The Arenillas block

To the north, it comprises continental quartzites and gneisses, which contain sillimanite in some places, as observed in traverses on the Chilla road (Edgar Salazar and Pablo Duque), the Río Negro-Pacca road (J. Aspden and F. Viteri), and in boulders derived from the southern sector of the Palenque River area, and along the Jubones River in the vicinity of the Porotillos National Park. To the west, along the Jubones road, 0.3 km west of Chicha, black phyllites and protomylonitic quartzites with a steep dip (80° strike) could mark the western limit of the block in this area.

To the south, the group found the Arenillas amphibolite and the semipelitic gneisses of La Avanzada. The latter demonstrate a metamorphic banding, probably superimposed on stratification, which is found folded along subvertical shears with close spacing and an E strike, producing antiform and synform structures with wavelengths of several meters.



The Raspas Subduction Complex

The group visited the outcrops of the Raspas blue schists and the El Toro harzburgite. A study was conducted on the contact south of the Raspas blue schists with the “Piedras Group” of “Precambrian” age, along the Playón-Balsas road near the bridge over the Naranjo River, east of Feininger’s map. The following changes occurred:

- (1) 2.4 km N of the Naranjo bridge: blueschists with penetrative S2 cleavage.
- (2) 2.1 km: graphite-muscovite schists with sub-penetrative S2 cleavage.
- (3) 1.7 km: Raspas blueschists.
- (4) 1.4 km: greenschists (Piedras Group) with penetrative S2 cleavage.
- (5) 0.8 km: greenschists.
- (6) Naranjo Bridge: greenschists.
- (7) 1.0 km S of the Naranjo bridge: mylonitic greenschists.
- (8) 1.6 km: mylonite.
- (9) 2.3 km: tectonized amphibolite/metagabbro.
- (10) 2.9 km: migmatite.

Based on these observations, the group preferred to include these greenschists within the Raspas Complex. The mylonite belt that separates the Raspas Complex from the higher-grade metamorphic rocks of the Palmales block could be interpreted as marking the same line of the ancient continental margin along which the Raspas Complex was accreted.

The La Bocana Block

Only the southern margin of this block was examined; however, the following observations could have regional significance:

- (1) Its southern margin is marked by amphibolites previously correlated with the “Piedras Group”. The northern contact is found marked by a mylonitic zone with the greenschists of the Raspas Complex (above).
- (2) This amphibolite/amphibolitic gneiss to the north can be traced along the fault toward the outcrops south of Portovelo.
- (3) The amphibolites pass toward the south (south of Piedras) into garnetiferous pelitic gneisses that are incipiently migmatized. To the south, in La Bocana, there are banded migmatitic gneisses and deformed para-autochthonous granites. These migmatites were previously correlated with the “San Roque Formation” of the “Tahuín Group”.



- (4) Along the fault to the east, south of Portovelo, the amphibolite passes southward into quartzites and semipelitic gneisses (San Roque "Formation"). Near Porotillo, there is a sharp change to low-grade slates with weak cleavages: the Capiro "Formation". The group was convinced that the San Roque rocks are the basement for the Capiro rocks.
- (5) The Capiro "Formation" south of Raspas was not visited. From Feininger's map, the change in grade also indicates a cover/basement relationship vis-a-vis with the San Roque gneisses. Toward the south, the Capiro rocks pass into non-metamorphosed fossiliferous Palaeozoic units (Feininger, 1978).

Notes for Interpretation

- (a) The Palenque ophiolite complex is an excellent candidate for the outlet of the Calacalí-Pallatanga suture, which we suggest marks the eastern limit of the Nono-Shobol terrane (Megard and Lebrat, 1987) south of Pallatanga.
- (b) In this interpretation, the Chaucha terrane (Feininger, 1987) would not be separated from the Biron terrane by the Jubones suture, but would instead form a single block: the Chaucha-Arenillas terrane, surrounding the Arenillas cratonic block.
- (c) The Raspas complex is now the logical correlation for the collision sequence of the Western belt of the Cordillera Real. Despite the Western belt being apparently thinner in El Oro, the mylonitic contact zone south of the Raspas complex, which separates it from the Palmales block, represents the logical SW extension of the Baños front of the Cordillera Real. It is possible that the polymetallic mineralization of Portovelo and Fierro Urcu is a continuation of the Ag-Cu-Zn-Pb mineralization related to the Baños front observed in the Cordillera Real.
- (d) The La Bocana block is probably of Precambrian age judging by the high-grade elements represented. It is possible that the Palmales and Chaucha-Arenillas blocks are derived from the Arequipa massif off the coast of Peru (Shackleton et al., 1979).
- (e) The contact between the San Roque gneisses and the Capiro phyllites is probably not a metamorphic transition, but rather a basement/cover relationship.

**JULY 12****Sabanilla (Zamora)-Loja-Catamayo**

In the southern sector of the Cordillera Real, semipelitic rocks comprise an important element of the metamorphic geology. This belt, the Loja semipelitic division (see First Annual Report, Cordillera Real Project, 1987), consists primarily of a thick and monotonous sequence of quartzites, phyllites, and slates. They are of a uniformly low metamorphic grade and are presumed to overlie basement gneisses and older migmatites (Precambrian?). Unfortunately, heavy rains and landslides prevented the group from examining part of the basement complex that is exposed to the east between Sabanilla and Zamora.

To the east, in the semipelitic rocks, the stratification and cleavage (S₁) are parallel and steeply inclined with Cordilleran strikes. A weak subhorizontal S₂ crenulation cleavage is also present, but as one moves toward the west in the area immediately east of the Tertiary Loja basin, this S₂ cleavage becomes markedly better developed and produces a "flat belt". To the west of the Loja basin, along the road to Catamayo, a strong, essentially flat S₂ cleavage is visible, related to tight F₂ folds. Subsequently, this has been gently refolded, but the original S₂ cleavage was probably related to some form of horizontal tectonism that affected the western portion of the Loja semipelitic division.

Along the western margin of the Loja basin, approximately 500 m of gneissic quartzites with minor amounts of biotite schists are exposed on the main Catamayo-Loja road. These are in fault contact with the lower-grade semipelites to the west and are probably related to the basement sequence, outcrops of which can be observed toward the north along the Loja-Saraguro road.

JULY 13

The group flew from Catamayo (7:00 am) to Quito (10:00 am).

Dr. John Aspden

APPENDIX 10

Field commission reports for the Cordillera Real from north to south

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No. 1934 D – G

QUITO, MARCH 28, 1988

TO : GERENTE TÉCNICO, ENCARGADO

DE : RAMIRO BERMÚDEZ

SUBJECT : Technical Report of the commission carried out at the Antisana River, headwaters of the Cosanga River, from January 18 to 28 of the current year

SUMMARY:

The Geological Research Project of the Cordillera Real, executed with technical assistance from the British Mission, carried out this service commission to conduct a geological study of the southern zone of the Antisana Volcano, northeast of the Antisana River (headwaters of the Cosanga River), and to correlate it with the regional geological framework of the Cordillera Oriental.

Reconnaissance was performed on the most conspicuous outcrops in the area, which ultimately proved to be the most suitable sites for checking the geology. The study was hindered by very thick and dense vegetation (*carrizales* and *sigsales*); the exotic blocks found in the small unnamed river are the most interesting, as they correspond to basic, ultrabasic, and carbonate rocks.

In outcrop, the rocks correspond to serpentinite, metalavas, chloritic-muscovitic-graphitic greenschists, and micro- to macro-granular quartz-feldspathic rocks.

Approximately 40 rock samples and 13 heavy and fluvial sediment samples were collected for their respective analysis and study.

1. INTRODUCTION

1.1 Objective

Geological study of the southern zone of the Antisana Volcano (headwaters of the Cosanga River).

1.2. Assigned personnel consisting of:

Ing. Ramiro Bermúdez A. (INEMIN)

Dr. Martin Litherland (ODA)

Sr. Manuel Celleri (prospector/INEMIN)

Sr. Oscar Acosta (Vehicle driving and maintenance/INEMIN)

A Jeep Land Rover AT-0056 belonging to the Mission was used for transportation.

1.3. Geographical aspects

The study area is located east-southeast of Quito, approximately 90 km away. Most of the route is traversed via second and third-order roads; the end of the road is approximately 60 km from the town of Píntag (2890 mamsl) on the left bank of the Antisana River (8129-9329). The remainder of the journey to the headwaters of the Cosanga River is done on foot, crossing the Andean páramos which constitute the majority of the area; the study zone belongs to the provinces of Pichincha and Napo.

1.4 Climate and Vegetation

The study area corresponds to the Cold Andean climatic zone, where páramos and pajonales (3800-4000 mamsl) are found. The vegetation is represented by: *achupallas*, *chuquirahuas*, *togros*, and large sectors of *carrizales* and *sigsales*.

1.5. Hydrography

The main hydrographic axis is the Antisana River, which originates in the foothills of the volcano (4400 mamsl) that bears its name. There are also other large tributaries (unnamed) that originate in the high zones and join the Antisana River, which to the south joins the Valle Vicioso River to form the Verdeyacu River.

1.6 Population

The inhabitants of the areas surrounding the Antisana River, El Carmen (3250 mamsl) and San José, are dedicated to agriculture and livestock farming, as well as small-scale cheese making and the slaughter and breeding of bovine cattle.



1.7 Roadways

The paved Quito-Píntag road constitutes the link toward the study area (33.5 km); from Píntag to the end of the road (60 km) is a paved road, which for the most part is new, built for the execution of the drinking water project (EMAPQ).

From the end of the road, the approach to the study area is carried out via footpaths or natural trails for the most part.

1.8 Land use

The majority of the soils are dedicated to agricultural and livestock activities: El Carmen, Hacienda La Cocha, and its surroundings. In the investigated zone, there are areas that could be dedicated to agriculture, but due to the lack of a penetration road, these remain unused.

1.9 Industries

They are completely absent.

1.10 Previous works

- Sauer W. (1965) Geología del Ecuador, Quito.
- INEMIN (1987) Geological Sheet of Píntag (No. 85) scale 1:100000, provisional publication.

1.11 Work methodology

- “In situ” geological observations.
- Collection of rock samples for their respective petrographic study or chemical analysis, and sampling of fluvial and heavy sediments

The Laguna de Micacocha topographic sheet was used, scale 1:50000, edited by the IGM; and aerial photographs covering the area, scale 1:60000.

2. GEOMORPHOLOGY

In this region, there are abrupt changes in morphology, with broken terrain and peaks that reach 4000 mamsl, that correspond to the Cordillera Real Terranes. Strong winds, rains, and frosts characterize these zones.

The morphology in the investigated area has undergone the action of glaciers, forming large cirques and glacial terrains, including lagoons that are easily observed in aerial photographs.

3. GEOLOGY

3.1 Introduction

The reconnaissance carried out in the south of Antisana, toward the northeast headwaters of the Cosanga River, was performed with the aim of studying the rocks belonging to the metamorphic and non-metamorphic complex of the Cordillera Real in its “Central Belt”, and to correlate them within the regional geological context.

It is worth noting that during the stay in the field, the weather was good with sparse precipitation and travel without difficult obstacles (paths and trails), which benefited the execution of the planned work.

Basically, the geological study comprises the location and study of “in situ” outcrops; and the study of exotic erratic blocks (certain sites).

The description and location are hindered by the lack of names for the rivers and streams, which have not been named on the Laguna de Micacocha 1:50000 (topographic) sheet.

The description of the geology of the area is divided into the metamorphic complex and the description of the boulders. From the panning in the rivers and streams, no presence of gold was observed, perhaps due to the fact that these rivers are short-run and traverse low terrains, young terraces, or are affected by landslides that do not allow for quiet sedimentation.

3.2 “In situ” Metamorphic Complex

Most of the metamorphic rock outcrops are located to the northeast and east of the Antisana River, and correspond to low and medium-grade rocks.

3.2.1 Metagranitoid rocks

Medium to coarse-grained rocks, located north and east of the Antisana River; in the outcrop (8174-9325) there are coarse-grained, micaceous quartz-feldspathic rocks with blue quartz.

In the observations made on a new wall resulting from a recent landslide (8195-9318), these whitish-grey, medium to coarse-grained rocks present quartz veins and “augen” type structures. The outcrop of these granitoid rocks is possibly the entire western wall that runs along the river.

The outcrops (8213-9297), located east of the Antisana River, are coarse-grained whitish-grey rocks; their walls are found intercalated with quartz and carbonaceous material, and micaceous quartz-feldspar. These granitoid rocks are massive, compact, and morphologically prominent as they appear as true walls (3940 mamsl).



3.2.2 Metasedimentary rocks

The outcrop (8176-9326), which is approximately 15×80 meters, is composed of lead-grey to whitish, massive, and highly “fractured” rocks; within them, an accumulation of calcareous material (concretions) is found. These rocks are the product of recrystallization from regional contact metamorphism, possibly of limestones or dolomites. The rocks are impure marbles. A characteristic of the area is the presence of carbonate material coming into solution in the waters and being deposited on the outcrop walls. Probably toward the eastern end of the Cosanga River headwaters (8266-9318), there is a core that may be composed of carbonate rocks (?).

At coordinates (8165-9325), the outcrop consists of grey to black phyllites; (8217-9331) is characterized by the presence of a low percentage of graphite, as well as quartz veins. These outcrops characteristically present highly altered walls (Fe_2O_3 ... / oxidation). The outcrops are found exposed because they are not covered by thick layers of volcanic deposits.

3.2.3 Metavolcanic rocks

The outcrops of these rocks (8159-9321) are composed of greenish rocks with chlorite, quartz, and micaceous feldspar corresponding to greenschists, metatuff type, intercalated with siltstone bands. Deformed volcaniclasts (relict texture) were observed in the respective thin section. The protolith of these greenschists is probably of igneous origin.

In the stream (8182-9321), greenish-grey, subhorizontal rocks were observed, chloritized metalavas, with the presence of disseminated sulphides; these metalavas are “cut” by whitish-grey, coarse-grained quartz-feldspathic rocks belonging to metagranitoid rocks, which are compact and massive, forming a tabular body.

3.2.4 Ultrabasic rocks

Rocks found in outcrop (8160-9321) at approximately 4150 mamsl, appearing as a “window” in the Cordillera Real. The rocks are massive, dark greenish-greys, with a N-S strike/dipping to the west; this outcrop corresponds to serpentinites (antigorite). These serpentinitic rocks lie above the black graphitic phyllites, being exposed from the volcanic cover and manifesting as true peaks that are conspicuous in the area. These rocks as a whole are related to the green metalavas.

3.3 Metamorphic Complex in blocks

Most of the collected blocks were taken from the streams or rivers that join the main Antisana River.

3.3.1 Metagranitoid blocks

Blocks of medium to coarse-grained quartz-feldspathic rocks are characterized by the presence of disseminated sulphides and crystallized pyrite. The blocks are whitish-grey in colour.

3.3.2 Metavolcanic blocks

The blocks correspond to altered mafic metalavas, with the presence of epidote (353A, 353I, 353J); these form the majority of the lithology of blocks in this small drainage. In general, some “metalava” blocks contain sulphides, magnetic minerals (Fe_3O_4), and their characteristic colour is pale grey to greenish-grey. These blocks are located at the grid coordinates (8195-9305).

Epidotized rock blocks (high percentage) with sulphides (uncommon), altered (353A, 353G), are found on the path to the mouth of the river that joins the main branch (8195-9308). These green metalava blocks could be related to the rocks of the Río Mulatos metalava complex (?).

3.3.3 Ultrabasic blocks

Blocks of serpentinite (antigorite) with carbonates (353F) of greenish-grey to black colour were found; although they are not common in the area (8195-9305), the origin of these blocks is probably nearby, as the morphology of the stream is gentle, opening up with terraces located at various levels and without a great difference in elevation.

Furthermore, an erratic block (353H) was found, composed of elongated fibrous green minerals (amphiboles) altered to talc, which is uncommon in the riverbed (8201-9306). In the field, the assembly of these blocks forms the base of the alluvial river terraces, which also possess a high percentage of oxidation.

3.4 Structure of the Metamorphic Complex

The structure of the area corresponding to the metamorphic complex suggests the presence of an antiform with gentle to moderate dips of tectonic foliation on its flanks. These flanks are composed of ultrabasic rocks (serpentinites), green metalavas, schists, and phyllites (W); toward the other flank (E), they appear with the same characteristics, and the antiform would have medium to coarse-grained metagranitoid rocks as its core. This suggests the presence of large “overthrusts” in the sector.

The direction of these overthrusts remains to be elucidated, which will help clarify the previous interpretation of the zone.

3.5 Coverage rocks

Recent volcanics: the rocks and deposits belonging to the volcanics originating from the Antisana Volcano are restricted to the western sector of the area. For the most part, they correspond to columnar lava flows covered by thick pyroclastic mantles that partially cover the Metamorphic Complex of the Cordillera Real.



4. ECONOMIC GEOLOGY

4.1 Metallic minerals

4.1.1 Gold

It was not observed during panning, possibly because the selected sites were not the most “suitable” due to the formation of low terraces and soils with a high amount of gravel; in any case, the respective chemical analyses will determine its presence or absence.

4.1.2 Pyrite/Chalcopyrite

In the green, epidotized metalava blocks, the presence of disseminated and crystallized sulphide mineralization (pyrite/chalcopyrite) is observed.

In quartz-feldspathic greenschist blocks, the presence of disseminated and crystallized sulphides (pyrite and chalcopyrite) is also observed, related to the quartz veins.

4.1.3 Magnetite

There is the presence of magnetic minerals (Fe_3O_4), black minerals with triangular faces and metallic lustre.

4.2 Non-metallic minerals and rocks

4.2.1 Asbestos

Green elongated amphiboles of asbestiform structure, altered to talc, were found sporadically. It is possible they are part of the set of green rocks collected in the riverbed (8201-9306).

4.2.2 Carbonate

In outcrop, there are impure marbles, which are the result of the recrystallization of calcite or dolomite (metamorphism). It is common to find the outcrop walls covered in carbonate (precipitation), but no calcite crystals were detected in the field.

5. RECOMMENDATIONS

Continue exploration toward the east to attempt to locate “in situ” the various lithologies found: green metalavas, serpentinite, epidotized rocks, etc., which, due to the short duration of the commission, were not possible to explore further.

Conduct detailed studies on the structure of the area (antiform) and attempt to determine the direction of the overthrusts.

Ing. Ramiro Bermúdez A.

CORDILLERA REAL PROJECT

No. 5400

QUITO, DECEMBER 01, 1987

TO : GERENTE TÉCNICO

FROM : RAMIRO BERMÚDEZ and MARTIN LITHERLAND

SUBJECT : Technical Report of the commission carried out to Salcedo-Las Carmelas-Mulatos River, from September 28 to October 8, 1987, in order to locate the "skarn belt in situ"

SUMMARY:

The Geological Research Project of the Cordillera Real, in its First Annual Report (March, 1987), reported lithologies of "exotic" blocks located in the Mulatos River (Section 4: Salcedo-Tena) belonging to skarn-type rocks; this service commission was carried out in order to locate these blocks "in situ".

In the El Placer River sector upstream, the pale skarn belt was located in situ ("Las Arenillas") with the presence of carbonate, and sectors that were epidotized with garnet and disseminated sulphides for the most part. Additionally, metamorphic rocks were observed: greenschists and graphitic schists with sulphide mineralization, which is common, metalavas with biotite, low grade of metamorphism, and yellowish-cream coloured intrusive rocks that are highly altered and fractured. This sector from the "San Martín" base (El Placer) at 2250 mamsl to "Las Arenillas" (2950 mamsl) is characterized by being a very dislocated and unstable area; along its path, a countless number of large blocks are found that have fallen from the highest parts, as well as landslides that hinder continuous monitoring of the rocks belonging to the skarn and their relationship with respect to the other rocks.

Around 50 samples have been collected for their respective mineralogical-petrographic and compositional (chemical analysis) study.



1. INTRODUCTION

1.1 Objective

Locate “in situ” the lithology of exotic blocks belonging to the “skarn belt”.

1.2 Assigned personnel

Comprised of Brigade No. 1

Ing. Ramiro Bermúdez A.	INEMIN
Dr. Martin Litherland	ODA
Sr. Manuel Céleri	Prospector/INEMIN

A Jeep Land Rover AT-0068 from the mission was used as transportation.

1.3 Geographical aspects

The area is located southeast of Quito, approximately 120 km (Salcedo), and toward the east as far as the sector known as Las Carmelas (Km 60, 2850 mamsl). This stretch takes approximately two and a half hours from Salcedo and belongs to the provinces of Cotopaxi and Napo.

1.4 Climate and vegetation

The region comprised between Las Carmelas (2850 mamsl) and Tambo de los Leones (3150 mamsl) is characterized by the presence of precipitation, winds, and a temperate Andean climate.

The area between the Zapalá (2330 mamsl) and El Placer (2850 mamsl) rivers has a temperate to subtropical climate and heavy rainfall, especially during these months (August/October) which correspond to “winter” in this zone.

The vegetation of the area is characterized by the presence of large forests and a wide variety of subtropical flora.

1.5 Hydrography

The main hydrographic axis is the Mulatos River, which is mostly torrential and very rugged, receiving the following rivers as tributaries: Zapalá and El Placer.

1.6 Population

The settlers (small in number) are engaged in agriculture, livestock, and timber exploitation; this occurs in the stretch between Tambo de los Leones and Las Carmelas. The rest, toward the easternmost sector, is uninhabited (Zapalá River–El Placer River).

1.7 Roadways

The Pan-American South (first-class road) Quito-Salcedo, 120 km, constitutes the link to the zone; from here to the Las Carmelas sector is 60 km, via a second-class road, mostly ballasted.

From Km 60 to the El Placer River, travel is conducted via a trail and along the bed of the Mulatos River, which makes rapid progress difficult.

1.8 Land use

A high percentage of the soils are dedicated to agricultural and livestock activities (Las Carmelas); the rest remains pristine (subtropical jungle).

1.9 Industries

Due to the lack of an adequate access road, industries are completely absent in this area (Las Carmelas-Mulatos River).

1.10 Previous works

- Sauer W. (1965), Geología del Ecuador, Quito
- Bermúdez R. y Litherland M. (1986), INEMIN, Informe técnico de la comisión al corte 4: Salcedo-Tena. No publicado.
- Litherland M. (1987). First Annual Report, Cordillera Real Project

1.11 Work methodology

The methodology followed was:

- “In situ” geological observations
- Study of structures
- Collection of samples for chemical and petrographic analysis
- Determination of the extent of the “skarn belt” outcrop

Topographic sheets at 1:50000 scale of Laguna Antejos were used, as well as planimetric sheets of Chalupas (152) and Mulatos River (160) at 1:50000; edited by the IGM, and aerial photographs covering the area at scales of 1:40000 and 1:60000.



2. GEOMORPHOLOGY

The area is characterized by:

- Zones with steep slopes and deep ravines in the “El Placer” (2950 mamsl) to Las Arenillas (2950 mamsl) sector; forming true ridges (*cuchillas*) that descend from the highlands (ca. 3000 mamsl), the area in which the “skarn belt” was located.
- Zones with moderate to gentle slopes, especially along the Mulatos River, but hindering travel due to the large number of loose blocks that are a hazard for walking (rain, mud, moss, etc).

3. OBJECTIVES AND SOURCES OF INFORMATION

The commission was designated solely to locate outcrops of “skarn” type rocks. Blocks of this lithology were observed in the Mulatos River and its tributaries during the “Salcedo-Tena” commission (Litherland and Bermúdez, 1986) and, later in the Paracayacu River (Niágara Grande) and tributaries (Merlyn and Cruz, 1986) further south. It should be noted that “skarn” outcrops had not yet been found in the Llanganates zone until this study. Although gold had not been seen in the pan in the area, a selection of “skarn” rocks and associated mineralized rocks were analyzed in the INEMIN laboratories for gold, yielding values from 1 to 14 ppm Au (Litherland, 1987).

There is a summary of the results of the investigation of the “skarn” blocks in Litherland (1987), of both economic and geological interest. This summary is based in part on petrographic studies under the auspices of B. P. Minerals International in England. Recently, results from heavy mineral sample studies arrived from the same company. Most of the petrographic data in this report are based on a petrographic study done under the auspices of B.P. Minerals International. These results and those of the heavy minerals will be presented in the Second Annual Report of the Cordillera Real Project in 1988.

4. TOPOGRAPHIC NOMENCLATURE

The four main ravines that join to form the El Placer River have been “baptized”, as has the mountain range that forms the highlands. This facilitates the description of the geology of the zone.

5. GEOLOGY

5.1 Regional geology

This comprises gneisses and schists of various lithologies found in situ along the Anatenorio and Mulatos rivers (Litherland and Bermúdez, 1986; Litherland, 1987). They include augen gneiss, biotite-muscovite gneiss, graphitic and muscovite schists, quartzites, and amphibolites. Garnet mineral may be present in all these lithologies. Going down the Mulatos River, there are outcrops of hornblende-biotite gneiss, which is interpreted as metatonalite/diorite. In several sectors of the Mulatos River, the gneisses have mylonitic aspects. Gneisses of metaplutonic origin have been correlated with the Azafrán igneous phase (Litherland, 1987).

In these rocks outcropping in the Anatenorio and Mulatos rivers, the subvertical tectonic foliation is related to D₂, with the exception of the outcrop in the Langoa cave which has a gentle dip related to D₃ refolding.

5.2 The geology of the El Placer River below the skarn

In the El Placer River (Fig. 1) there are no outcrops below the junction of the “tributaries” (San Martín, San Manuel, etc.). Higher up in the ravines, graphitic and muscovite schists and “semipelitic” mylonitic gneiss outcrop with tectonic foliation dips (S₂) of 30° to 70° to the west. Further up, but below the “skarn” sequence, there are large blocks originating from landslides of a massive, medium green, andesitic “metalava” type amphibolitic rock with biotite megacrysts and an outcrop of this rock with tectonic foliation. The rock resembles a lamprophyre, but the quantity of blocks and the appearance of the outcrop indicate a new metalava instead of a metadyke. At the mouth of the Zapalá River, there are many blocks of this lithology. Between this metalava and the gneisses, there are angular blocks and outcrops (in situ?) of a black “tiger rock” type marble with calcite veins that weather to a yellow/brown colour.

5.3 The “skarn” sequence in outcrop

There are large blocks of skarn in the El Placer River, and both because of this observation and its limited drainage basin, this river was chosen for the search for outcrops. It should be noted that there are skarn blocks in the tributaries further south, which are less accessible and have very large drainage basins to explore. In the El Placer River, the blocks disappear for a distance above the junction of the ravines, reappearing in the “San Martín” Ravine at an elevation of 2600 m.

Along the “San Martín” Ravine, the “skarns” outcrop at elevations of 2900-3100 m (Fig. 2) and there were blocks of skarn and metaintrusive in the ravine at the end of the traverse (3100 m); presumably there is more “skarn” above 3100 m.

Outcrops of other lithologies of the “skarn” sequence show low-angle tectonic foliations/schistosity (0°-25°), and therefore the sequence can be treated as a horizontal layer (Fig. 2).



“True” skarns (Fig. 2) are found in three waterfall-type outcrops. In the two lower outcrops, the skarn rocks are of the “pale” type, showing pinkish colours (garnet), clinopyroxene (pale green), and amphibole (dark green-black). They are associated with skarns of clinopyroxene-amphibole-epidote rock of medium green colour; and medium green amphibolite with strong calcium metasomatism (amphibole, epidote, garnet, magnetite). There is also a sample of quartz-grossular rock that corresponds to a sedimentary protolith. Most of the other samples have a protolith that corresponds to a fine mafic rock, possibly andesitic.

Higher up there is a 3 m band of skarn with clinopyroxene-epidote-magnetite and epidote types.

Other rocks that outcrop (Fig. 2) are pelitic schists, graphitic schists with garnet and biotite, siliceous marble, metadiorite, and a plagioclase rock probably of andesitic origin. These last two are strongly affected by metasomatism.

5.4 The skarn sequence and other lithologies in float blocks

In the Mulatos River and the El Placer River, the most common skarn blocks are of the pale type dominated by garnet, epidote, and clinopyroxene. Along the El Placer River, these blocks can be the size of a house. Other block lithotypes not seen in outcrops are the following:

- (a) Serpentinites (No. 261), one with a vein (12 cm) of magnesite (No. 262), only in the Mulatos River (Fig. 1).
- (b) “Tiger rock”: in the El Placer River and San “Manuel” Ravine, there is an abundance of marble and “skarn” rocks with carbonate veins parallel to the foliation which weather to a yellow/brown colour. Another type is a black phyllite calcilutite with carbonate layers (1-5 cm) with yellow/brown weathering.
- (c) Graphitic siliceous marble (No. 280): in the El Placer River, black in colour and fine-grained with sphalerite.
- (d) Diopside skarn (No. 274) in the San “Manuel” Ravine: angular blocks associated with metalavas. Rock named diopsidite. It could be of serpentinitic protolith.
- (e) Skarn breccia (No. 281): in the El Placer River: with dark “clasts” of epidote-amphibole-calcite composition assimilated by zones rich in epidote. Magnetite (approx. 10%) is the dominant opaque mineral.
- (f) Meta-agglomerate (No. 272): in the San “Arturo” Ravine: gneissic quartz-feldspathic rock with muscovite, with angular clasts (up to 4 cm long), volcanic glasses with porphyritic feldspar.
- (g) Quartz: blocks of up to 100×50×50 cm of quartz vein, one (No. 276) from San “Gonzalo” Ravine with galena.



- (h) Pyrite schists: in the Mulatos River (No. 265), with muscovite, epidote, quartz, pyrite (25%), and phlogopite; and in the El Placer River (283) with chalcopyrite.
- (i) Igneous dike (282): in the El Placer River, blocks of 50×30×20 cm in size of pale microfeldspathic dike without mafic minerals.
- (j) Epidotized calcareous schist (286): Mulatos River with quartz, epidote, actinolite, garnet, chlorite, pyrite, and sphalerite.
- (k) Altered amphibolite (267A): Mulatos River, with alteration by garnet, epidote, pyrrhotite (7%), and amphibole. Chalcopyrite is present.
- (l) Clinozoisite skarn (267H): Mulatos River, almost monomineralic pink rock.
- (m) Impure marble with porphyroblastic garnet (265A): Mulatos River; with garnets of 1 cm in diameter in a carbonate matrix.
- (n) Tourmalinite (269B): Mulatos River, black, schorl-dravite with chalcopyrite.

5.5 Structure

The change in attitude of the tectonic foliation from the Mulatos River to the “Serranía Arenillas” is the key point to explain the presence of the “skarn” sequence and interpret its extension. In the Mulatos River, the tectonic foliation is subvertical and steeply dipping to the West. Going up the El Placer River, the angle changes to 30°-50° to the west in the schists and gneisses. Higher up in the “skarn” sequence, the tectonic foliation is subhorizontal. In all parts, it can be shown that the tectonic foliation represents at least the second phase of deformation. The major change in the attitude of the foliation can be interpreted as a consequence of regional overthrusting.

5.6 The extension of the new skarn field “Serranía Arenillas”

The outcrops, with subhorizontal foliation, occur at 3000 m elevation along the crest of “Serranía Arenillas”. This “layer” cannot be followed by photogeological expression. The lack of “skarn” blocks in the Zapalá River (Fig. 1) suggests that the “skarns” are not exposed along the western flanks of the range (that is, through the Zapalá valley). Thus, the skarn sequence is tectonically limited on the eastern side. The presence in the Zapalá River of many “metalava” blocks of the type that outcrops below the skarns in the El Placer River (with biotite porphyroblasts) suggests that the “skarn” sequence has a synformal structure with a steeper western flank.

Further south of “Serranía Arenillas” there are “skarn” blocks in the Tigre and Negro Chico rivers. Higher up in this last river, there are blocks in its tributaries (Merlyn and Cruz, 1986). It is assumed that the skarn field extends with an Andean strike to this sector, but only in the highlands of the mountain range.



5.7 Origin of the skarns

The lithological characteristics of the “Serranía Arenillas” skarns correspond to the calcic magnetic skarn type (Einaudi et al., 1981), with an island arc origin. These characteristics are as follows:

- (1) The lithotypes found.
- (2) Association with epizonal dioritic intrusives.
- (3) Its epidote-grandite-ferroclinopyroxenite assemblage.
- (4) Epidote-pyroxene alteration of plutonic and volcanic rocks.

6. ECONOMIC POTENTIAL

6.1 Introduction

The presence of abundant sulphides is a characteristic of the “skarn” outcrops and blocks and their associated lithologies. The following information comes from field data and geochemical analysis.

6.2 Gold

The amounts of gold in rock indicated by INEMIN analyses in 1986 have not been confirmed by studies by two private companies. It seems that the skarn field is not a major source of gold, as indicated by the lack of gold in panning.

6.3 Silver

The highest value from stream sediment analysis by a private company is 0.206 ppm Ag.

6.4 Arsenic

The highest value from stream sediment analysis by a private company is 117 ppm, which comes from the El Placer River.

6.5 Copper

Small amounts of chalcopyrite have been noted in rock samples (e.g., 267A, 269B, 283).

6.6 Mercury

The highest value from stream sediment analysis by a private company is 0.204 ppm Hg from the El Placer River.

6.7 Molybdenite

The highest value from stream sediment analysis by a private company is 1.81 ppm Mo from the El Placer River.

6.8 Lead

Small galena mineralization was noted in a block from the San Gonzalo Ravine (No. 276). The highest value from stream sediment analysis by a private company is 15.2 ppm Pb from the El Placer River.

6.9 Zinc

Sphalerite was noted in the meta-andesite of the skarn sequence (292A) and in blocks (266, 280). The highest value from stream sediment analysis by a private company is 182 ppm Zn from the El Placer River.

6.10 Nickel

There is 7% pyrrhotite in sample No. 267A.

6.11 Iron

Magnetite is a component in samples 281, 286G, and 292A. In No. 292A, it comprises 15% of the rock.

6.12 Magnesite

There is a vein of magnesite? 12 cm thick in a serpentinite block (262).

6.13 Tourmaline

There is a small block of tourmaline (schorl-dravite) (269B).

6.14 Summary

The identification of “skarn” blocks (Litherland and Bermúdez, 1986) and their location in outcrops (this report) is a great step in the knowledge of the geology and mineral potential of the Llanganates. Geochemical studies and analyses so far have not found a mine deposit, but the mineralization observed in the studied samples and the probable extension to the south and north of the “Serranía Arenillas” skarn field indicates a favourable zone for mineral prospecting.

The serpentinite blocks may or may not be associated with the skarn sequence. These blocks were seen in the Mulatos River further upstream than the skarn blocks. In any case, the source of the serpentinite may also constitute a zone of mineral potential.



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Ing. Ramiro Bermúdez A.

Dr. Martin Litherland

CORDILLERA REAL PROJECT

ATTACH. Two maps

No. 0065

QUITO, JANUARY 11, 1987

TO : GERENTE TÉCNICO

FROM : RAMIRO BERMÚDEZ and MARTIN LITHERLAND

SUBJECT : Technical report of the commission carried out to Patate-El Triunfo-Cordillera de Los Llanganates, from November 9 to 20, 1987

SUMMARY:

The Cordillera Real Project is being executed under Technical Assistance from Great Britain. Within the programming scheduled for the second year, this service commission was planned from November 9 to 20, 1987, to Patate-El Triunfo-Cordillera de los Llanganates, in order to perform a geological-structural study of the Cordillera de los Llanganates in the Cerro Hermoso sector and correlate it within the framework of the Cordillera Real.

The rocks observed in the sections: Patate-El Triunfo-Río Muyo-"Cordillera"-Cerro Hermoso belong to metamorphic rocks that form the basement of the Cordillera: micaceous schists (biotite-muscovite-sericite) with quartz content, coarse-grained quartz-feldspathic rocks with muscovite (orthogneiss), black phyllites with carbonate enrichment and the presence of pyrite and chalcopyrite, and observing the formation of an iridescent patina on the pyrites, bituminous black limestones with intercalation of poorly sorted black sandstones – turbulence zone?; additionally, minerals such as magnetite and sulphides (pyrite-chalcopyrite) were observed associated with quartz veins ranging from centimetres to several meters. In certain sites, the schists contained garnets, iron minerals, and chlorite.

Furthermore, black tourmalines (schorl?) were found. It is common to observe, especially in the Cerro Hermoso sector, the presence of "caverns" in the black limestones caused by the circulation of water rich in carbonates or by the dissolution of the carbonates contained within the limestones.

Around 60 rock samples and 8 heavy and fluvial sediment samples were collected for their respective study.



1. INTRODUCTION

1.1 Objective

Geological-structural study of “Cerro Hermoso”.

1.2 Assigned personnel

The commission was composed of:

Ing. Ramiro Bermúdez A.	INEMIN
Dr. Martin Litherland	ODA
Sr. Vicente Navarro	Driver/INEMIN

We were also accompanied by Mr. P. Townsend from the company B.P. Petroleum, Quito.

A Jeep Land Rover AT-0068, belonging to the Mission, was used as transport.

1.3 Geographical aspects

The area is located south-southeast of Quito, approximately 190 km, from El Triunfo (2450 mamsl) to Cerro Hermoso (3840 mamsl) it was carried out via “mule track” and trail; taking 3 days to reach the study site which belongs to the Province of Tungurahua, Patate Canton, El Triunfo Parish.

1.4 Climate and vegetation

The study area corresponds to a climatic zone defined as high plateaus and mountains, cold type; thus, the El Triunfo parish (2450 mamsl) to Base 1 Río Muyo (2970 mamsl), belongs to a temperate Andean climate, with abundant rains throughout most of the year, with rich and varied vegetation, especially in cereals, tubers, pastures, wood, etc.

From the “Cordillera” Base (3730 mamsl), to the Cerro Hermoso sector (4500 mamsl), it corresponds to the Cold Andean climatic level, where the paramos and pajonales are located with vegetation represented by lichens, *frailejones*, ferns, etc.

1.5 Hydrography

The main hydrographic axis is the Muyo River, which originates in the Cordillera de los Llanganates under the name of Pucará and flows from north to south-southwest, waters that later discharge into the Río Verde Chico.

1.6 Population

The inhabitants of the El Triunfo parish and its surroundings are dedicated to agriculture, livestock, and timber exploitation. The section from Tres Cruces to Cerro Hermoso is completely uninhabited; it is only visited by travellers seeking to contemplate the landscape and nature of the area.

1.7 Roadways

The Pan-American South (a first-order road), Quito-Patate, approximately 160 km, constitutes the link to the area; from here to El Triunfo parish is 32 km, at 2450 mamsl, via a second-order road, which is paved for the most part.

From El Triunfo to Cerro Hermoso, the journey is made via paths and trails.

1.8 Land use

A high percentage of the soils are dedicated to agricultural and livestock activities, El Triunfo parish and its surroundings, the rest remains unused.

1.9 Industries

Due to the lack of an adequate access road, industries are absent in the area (El Triunfo-Cerro Hermoso).

1.10 Previous works

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1.11 Work methodology

The work methodology was as follows:

- “In situ” geological observations
- Study of structures
- Collection of samples for petrographic study and sampling of fluvial and heavy sediments

The Sucre topographic sheet was used, scale 1:50000, edited by the IGM, as well as aerial photographs covering the zone at a scale of 1:60000.



2. GEOMORPHOLOGY

The study area is characterized by having abrupt changes in its morphology over short distances, with broken terrain and peaks that exceed 3800 mamsl, nestled in the Cordillera Real, with strong winds, drizzles, and cold during this season which corresponds to “summer” in this zone.

The presence of true ridges descending from the high zones toward the foothills is characteristic in this area; additionally, there is the presence of headwater “cirques” resulting from glaciers.

3. GEOLOGY

3.1 Previous studies

Several scientific trips have visited Cerro Hermoso (Reiss and Stübel, 1886; Wolf, 1892; Andrade Marin, 1936; Loch, 1939). Sauer (1958) made the first detailed geological description with a schematic section through the mountain. Subsequent visits have been carried out by Kennerley (Kennerley, 1971; Kennerley and Bromley, 1971), and Vera and Vivanco (1983). The present study offers, for the first time, a geological map of the Cerro Hermoso area.

Sauer (1958) and Kennerley (1971) consider that a subhorizontal overthrust zone of a supra-vertical calcareous sequence exists over an older metamorphic basement. Vera and Vivanco (1983) also identify a subhorizontal cleavage parallel to the stratification in the calcareous unit and consider that the calcareous unit and the metamorphic basement have the same structural history.

This report is presented without the aid of microscopic slides (thin sections), which, when ready, will serve to expand the petrological scheme.

3.2 Geology of the metamorphic basement

Between El Triunfo and Cerro Hermoso (Map 1), this comprises pelitic and semi-pelitic garnetiferous schists and gneisses; amphibolites; augen gneiss of mostly plutonic origin, and graphitic schists. There are also blocks of serpentinites, hornblende gneiss, and granitoid gneiss with grey/blue feldspars.

This sequence is similar to those found to the south and north in the Pastaza and Mulatos rivers respectively (Litherland, 1987). The tectonic foliations are subvertical and there is no evidence of skarn rock blocks like those found tectonically overlying these same sequences in the highlands west of the Mulatos River (Litherland and Bermúdez, 1987).



In the Cerro Hermoso area (Map 2), the “metamorphic basement” comprises two lithologies. There is a metaplutonic type of metadiorite composition. In certain places, for example, SE of Laguna Australia, the appearance is that of a quartz monzonite. Near the regional faults the rock is a hornblende gneiss with or without garnet. This metaplutonic body that forms a part of the Cerro Hermoso basement can be correlated with the Azafrán intrusive to the south, which continues to the north in the Mulatos River (Litherland, 1987). It should be noted that, to the east of Cerro Hermoso, east of the main faults, the deformation/metamorphism decreases as was noted in the Pastaza and Mulatos rivers (Litherland, 1987).

The other lithology of the Cerro Hermoso basement is a pelitic schist dominated by muscovite and quartz, and in many places with garnet and chloritoid. This always demonstrates the same deformation/metamorphism which indicates that the plutonic intrusion is later and came after the formation of the schists.

3.3 The Cerro Hermoso sequence

This is demonstrated in the legend of Map 2. It comprises phyllites, quartzites, limestones, slates and at the top a “flysch” type unit. With the exception of the phyllites below, the sequence can be verified using sedimentary structures to determine the younging direction. With the phyllites below, the thickness of the sequence has a minimum of 540 m.

Map 2 shows that there are two outcrop zones. Passing through Laguna Walther Sauer the sequence outcrops as a belt of Andean strike and with subvertical dip. It is logical to deduce that this belt can continue to the north and south (Map 1). In contrast, the outcrop of the sequence by Cerro Hermoso itself is by synclines and restricted to elevations higher than 3700 m (see sections in Map 2). Due to this topographic control, it is doubtful that more outcrops exist along the Andean strike north or south where the terrain does not reach 3700 m in altitude.

The base of the Cerro Hermoso sequence has not been well defined in the field despite the good outcrops that exist especially above 4200 m. There are three interpretations:

- (1) That in the rocks of Cerro Hermoso there is no “basement” and supra-vertical sequence as interpreted by Vera and Vivanco (1983).
- (2) That a sedimentary or tectonic discontinuity exists between the metamorphic basement and the phyllites (No. 3 on Map 2).
- (3) That an unconformity exists at the base of the quartzites (No. 4 on Map 2).

In any case, there is a large change in metamorphic grade between the schists and the phyllites to support interpretation No. 2, although the contact between the two lithologies to the NE of Laguna Walther Sauer is abrupt, but does not appear tectonic.



There is a conglomerate at the base of the quartzite, along the shore of Laguna Walther Sauer (where there are also limestones), and to the SE of the same lagoon. But, upon a superficial examination, the clasts of the conglomerate are of black shale and not of phyllite or schist. Furthermore, the regional cleavage of the Cerro Hermoso sequence cuts the quartzites and continues into the phyllites below.

The metaplutonic rocks of the “basement” had never been seen cutting the “supracortical” sequence. Contacts between them are tectonic. However, the presence of andalusite and post-tectonic garnet in the “supracortical” sequence indicates late thermal metamorphism.

Taking into account everything noted above, the most probable interpretation would be No. 2, meaning the contact between the phyllites and the “basement” represents an unconformity or a tectonic plane. The lack of cleavages/tectonic structures parallel to this contact (i.e., subhorizontal structures) would indicate a sedimentary unconformity.

3.4 Structure

The scale sections (Map 2) indicate the geological structure around Cerro Hermoso. Within the supracortical sequence, these consist of vertical folds with low-angle plunges and subvertical axial-plane cleavage. No subhorizontal structures exist, neither in the form of overthrusts (Sauer, 1958) nor with a cleavage subparallel to the stratification (Vera and Vivanco, 1983). This structural aspect is especially noted in the western sector of the summit of Cerro Hermoso where the western flank of the Cerro Hermoso syncline demonstrates subhorizontal stratification (see Section A-B, Map 2). In this sector, the metamorphism is very low and only one tectonic structure is noted: the subvertical cleavage.

It is these subhorizontal layers which have given the false impression of subhorizontal tectonic structures to previous geologists. In this sector, the Cerro Hermoso syncline has a monoclinical form with the eastern flank being more or less steep. Further to the southeast, this fold becomes tighter (see Section C-D, Map 2).

The important faults shown in Map 2 are parallel to the cleavage in the supracortical sequence and appear to be related to the folding, meaning they are formed along the flanks of major folds, eliminating the fold noses.

It appears that the most fundamental fault is the Walther Sauer Fault, along which there is a metamorphic basement overthrust onto the younger sediments of the Cerro Hermoso supracortical sequence.

A low-angle crenulation cleavage is sporadically developed in both units (basement and supracortical). The basement rocks have a strong jointing at 110° and in the supracortical sequence the strike is more like 130° (see Vera and Vivanco, 1983).

3.5 Minor intrusions

There are quartz veins 10-20 m thick in the metamorphic basement along the joints with a 110° strike, which, in the sector SE of Laguna Walther Sauer, do not appear to continue through the supracortical sequence, where the calcite/quartz veins are normally subparallel to the cleavage.

3.6 Thermal metamorphism

Post-cleavage andalusite needles exist in the slates of the supracortical sequence (Map 2).

By the Cerro Hermoso fault and a secondary parallel fault about 30 m to the west, there are carbonate rocks with garnet. This mineral forms in specific layers of the limestone and slate sequence in the rocks next to the faults for one kilometre of strike. The layers are situated by the nose of a regional fold and have a low-angle dip. It can be seen that the presence of garnet in certain limestone layers is in one locality in the form of a lens 20 m long along the strike and up to 2 m thick and associated with a quartz vein.

3.7 Geological history

The following provisional sequence of events can be formulated taking into account the geological observations in Cerro Hermoso:

- (1) Formation of the basement schists.
- (2) Intrusion of the Azafrán pluton (metadiorites) which has given an Rb-Sr age of 120 Ma (written communication, Dr. C. C. Rundle).
- (3) Erosion and deposition of the supracortical sequence of Cerro Hermoso of Cretaceous age.
- (4) Faulting and folding of probable Tertiary age as part of the Subandean tectonic belt which affects the eastern Cretaceous Formations.

It should be noted that the Azafrán complex itself has given a K-Ar age of 171 Ma (Litherland, 1987).

In this interpretation the Cerro Hermoso zone is taken as autochthonous. If an overthrust fault exists between the basement and the supracortical sequence it would be at the base of the black phyllites.

It is difficult to explain the presence of andalusite and garnet as contact metamorphism from the Azafrán pluton, because the andalusite is post-tectonic (post-cleavage), and the cleavage itself is related to the faults that produce the gneissification of the Azafrán pluton.



Now, the studies of this commission have taken a great step toward the interpretation of the Llanganates. A large “tectonic nappe” of supracrustal rocks no longer exists, as was suggested in Kennerley (1971) and the National Geological Map (1982). In the photointerpretation of this sector by Kennerley (1971), glacial slabs of the Azafrán pluton were confused with the supracrustal rocks of Sauer (1958). This has now been proven in the field to the east of Cerro Hermoso and also by viewing from 500 m east of Laguna Australia: the hills to the east are of homogeneous rock, without stratification and with an igneous or meta-igneous appearance.

4. ECONOMIC GEOLOGY

During the traverses through Cerro Hermoso, the following indications and zones of mineralization were located.

4.1 Abandoned mining work

Map 2, approximately 3930 m amsl, outcrop of micaceous schists (biotite-muscovite) with quartz, pale-grey to greenish, oxidation zone Fe_2O_3 . Presence of fracture zones with quartz veins and with the presence of sulphides (pyrite and chalcopyrite) crystallized and disseminated. In past times, these quartz veins were exploited manually; currently, they are abandoned.

4.2 The “skarn” zone by the Cerro Hermoso fault

Map 2 delimits a zone of one kilometre where, due to two faults (see 3.6), there are lenses of metamorphic limestones with an abundant presence of garnet, associated with quartz veins. Sulphides exist in the garnetiferous marbles and indications of bornite in the quartz veins. The garnetiferous rocks are of the “skarn” type, but this zone and its dimensions cannot be compared with the tectonic skarn layer of more than 200 m thickness in the Río Mulatos area (Litherland and Bermudez, 1987).

4.3 Mineralization in other veins

The quartz veins that cut the metamorphic basement carry small sulphides. In the calcite/quartz veins that follow the cleavage in the limestones and slates of Cerro Hermoso, there are also sulphides with the presence of copper. Near the peak of Cerro Hermoso, there are blocks of green vuggy calcite with a little mineralization of smithsonite?

4.4 Mineralization related to the base of the quartzite

About 400 m SE of Laguna Walther Sauer, investigations to find the contact between the quartzites (No. 4 on Map 2) and the phyllites (No. 3) found along the contact a zone of quartzites and “schist” with quartz with sulphide mineralization, tourmaline?, and a mineral with strong reddish weathering. The zone, which has a thickness of no more than 20 cm, may be important vis-a-vis the interpretation of the base of the supracortical sequence, and microscopic studies are necessary to determine its petrological nature.

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Ing. Ramiro Bermúdez A.

Dr. Martin Litherland

CORDILLERA REAL PROJECT



No. 4483

QUITO, SEPTEMBER 14, 1987

TO : GERENTE TÉCNICO

FROM : RAMIRO BERMÚDEZ and MARTIN LITHERLAND

SUBJECT : Technical Report of the commission carried out from July 27 to August 14, 1987, to Riobamba, Guamote, Alausí and Azogues

SUMMARY:

The Cordillera Real Project, which is executed with Technical Assistance from the British Mission, carried out this service commission in order to continue, at this stage, with the studies of the zones investigated during the first year. The basic objective was to achieve better control of the geology and structure, which will result in a better understanding of the processes occurring in this Cordillera regarding the belts: Western, Central, and Eastern.

Basically, the areas belonging to the following sections were visited: Guamote-Macas, Licto-Huamboya, Alausí-Guasuntos-Achupallas, Zula-Laguna de Cubillín, and toward the south: Cañar-Taday-Pilzhum, etc. Approximately 120 samples were collected for their respective study.

1. INTRODUCTION

1.1 Objective

Define a better lithological-structural control of the belts pre-established in the first year.

1.2 Assigned personnel

Brigade No. 1 comprised of:

Ing. Ramiro Bermúdez A.	INEMIN
Dr. Martin Litherland	ODA/BGS
Sr. Mario Núñez	Vehicle driving and maintenance/INEMIN

A Land Rover Jeep AT-0068, belonging to the mission, was used as transport.

1.3 Previous works

The following geological map sheets at a 1:100000 scale were used: Alausí (71) 1975, Cañar (72) 1975, Chimborazo (69) 1976, Ambato (68) 1978, Riobamba (70) 1978 and Baños (88) 1980; sheets on which the mapping of the metamorphic rocks of the Cordillera Real was carried out.

Additionally, all information obtained by the Project during the first year of studies was used (First Annual Report, Cordillera Real Project, March 1987).

1.4 Work methodology

The following cartographic bases were used: Cola de San Pablo, Guamote, Totoras, Palmira, Alausí, Riobamba, Guano, at 1:50000 scale, published by the IGM, and 1:60000 aerial photographs covering the area.

The work methodology was:

- In situ geological and structural observations
- Studies of river cobbles and boulders
- Collection of samples for petrological study (thin sections)

1.5 Geomorphology

The geomorphology of the area is characterized by having zones with steep slopes and deep ravines that make ascent and descent difficult within a few meters.

1.6 Geographical aspects

The areas studied in this commission are located in the provinces of Chimborazo and Cañar, toward the eastern end in the foothills of the Cordillera Real.

1.7 Climate and vegetation

In general, the visited area varies in relation to the elevations, as follows: from 2700 meters above sea level to 3500 meters above sea level (Licto, Alao, etc.), with an Andean temperate to Andean cold climate and temperatures fluctuating between approximately 8 and 12 degrees Celsius. The vegetation is closely related to the climate; in the Andean temperate to cold zone, the vegetation is typical of the paramo: grasslands (pajonales), scrub (chaparro); with crops of potatoes, barley, wheat, etc.

1.8 Hydrography

The main hydrographic axes are represented by: the Alao, Huarguallá, Chambo, Cebadas, and Maguazo rivers (Licto-Alao sector) and the Zula River (Guasuntos-Achupallas).

1.9 Population

The inhabitants of these areas, including the communities, are dedicated to agricultural, livestock, and grazing activities. The highest concentration of the population is found in the following parishes: Achupallas, Guasuntos (Alausí canton), Penipe (Penipe canton), Cebadas, Palmira (Guamote canton), Licto, Pungalá (Riobamba canton), Taday (Azogues canton).



1.10 Roadways

The southern Pan-American Highway Quito-Ambato-Riobamba-Guamote-Alausí-Cañar-Azogues constitutes the link to the area (approximately 460 km; 8 hours).

Second and third-order roads were also used to connect the various parishes and settlements existing in the provinces of Chimborazo and Cañar: Riobamba-Licto-Pungalá-Alao; Alausí-Guasuntos-Achupallas-Zula, etc.

1.11 Land use

In the area, a high percentage of the land is dedicated to agricultural and livestock activities.

In certain sectors, existing materials (volcanic, metamorphic, and intrusive rocks) are used for the surfacing and maintenance of the roads.

2. OBJECTIVES

The commission was intended to complete the mapping of the lithological-tectonic divisions of the Alao Valley of the Western belt (Litherland, 1987) of the metamorphic basement of the Cordillera Real, and to follow them to the north and south as far as the outcropping allows, and until they connect with the studies of Aspden and Viteri in the south. In the Alao and Huarguallá valleys, some data on these divisions had been noted in 1986 in the Licto-Huamboya (Litherland and Bermudez, 1986a) and Guamote-Macas (Litherland and Bermudez, 1986b) sections, which were provisionally interpreted as a continent-continent collision zone (Litherland, 1987; Aspden et al., 1987). The preliminary informal divisions and their interpretation from west to east were as follows:

- (a) Guamote quartzitic division (continental sediments)
- (b) Cebadas black slate division (continental sediments)
- (c) Peltetec subduction complex (ophiolite and forearc volcanic sediments)
- (d) Alao-Paute greenstone and metasediment division (island arc)

Now, after this commission, the divisions are modified as follows:

- (a) Guasuntos black slate division (continental sediments)
- (b) Guamote quartzitic division (continental sediments)
- (c) Cebadas black slate division (continental sediments)
- (d) Peltetec ophiolitic division (oceanic crust)
- (e) Maguazo turbidite and andesite division (forearc)
- (f) Alao-Paute greenstone and metasediment division (island arc)
- (g) Guarumales metasediment and greenschist division (back-arc)

Another objective was to study subsequent Cretaceous-Recent rocks, such as the rocks named Macuchi Formation and Yunguilla Formation and their transition with the metamorphic complex reported by Bristow et al. (1975) in the Cañar geological sheet, as well as the Cenozoic volcanic rocks (the Alausí and Tarqui volcanics) in relation to the fundamental structures of the metamorphic basement.

3. ITINERARY

Month	Day	Traverse
July	27	Quito-Riobamba visiting the outcrop of the Macuchi Formation in the Cutuchi River (Ambato-68 geological sheet).
	28	Penipe (Chimborazo-69 geological sheet) to study the metamorphic window (see Map 2) and stream boulders in the Chambo River. Then to Baños to locate the Baños front.
	29	Yaruquíes (Riobamba-70 geological sheet) to see the Macuchi Formation window and then to Punín to study the metamorphic window.
	30	Guamote (Riobamba-70 geological sheet) to study the basement quartzites and the Macuchi Formation in the Columbe River. Then Guamote to Licto studying the section.
	31	Alao Valley, completing the section.
August	1	Alao Valley, studying the Peltetec ophiolite.
	2	Riobamba-Alausí, studying basement outcrops near the road and east of Palmira (Alausí-71 geological sheet).
	3 y 4	Studying the section along the Zula River (Guasuntos-Totoras).
	4 y 5	Through Osogochi (Cubillín Lagoon) looking for basement windows.
	7	Alausí-Azogues.
	8	Azogues-Cañar River-Pilzhum Mine (Cañar-72 geological sheet) studying the basement, Yunguilla, and Tarqui.
	9	Ingapirca-Río Silante (basement).
	10	Azogues-Río Paute (Azogues-73 geological sheet) studying the basement.
	11	Azogues-Taday-Guaraynag-Paute, studying the Yunguilla lavas and the Tampanchi mafic-ultramafic complex.
	12	Azogues-Riobamba.
	13	Huarguallá Valley, completing studies of the tectonic divisions in the basement.



4. GEOLOGY OF THE METAMORPHIC COMPLEX

4.1 The Guasuntos, Guamote and Cebadas divisions

These three divisions form the basement (metamorphic complex) west of the Peltetec fault up to the Ingapirca fault (Map 1), which was traced on the Cañar geological sheet to the north. It appears that no outcrops of these divisions exist west of the Ingapirca fault.

The Guasuntos, Guamote, and Cebadas divisions are lithological (not stratigraphic) divisions within a tectonic package of rocks of continental origin. The Guasuntos and Cebadas divisions are dominated by black/grey slates and the Guamote division by quartzites. The stratigraphic order and the possible lithostratigraphic correlation of the Guarumales and Cebadas divisions are unknown. No sedimentary structures have been found that could assist in this matter.

4.1.1 The Guasuntos division outcrops by the town of this name and to the east as far as Achupallas. It comprises black, grey, and pale slates with intercalations of fine to medium-grained black and grey quartzites.

4.1.2 The Guamote division outcrops from Punín in the north to the Silante River (near Ingapirca) and San Pedro River in the south. In the Cañar geological sheet it includes the Ingapirca Formation, previously included with the Yunguilla Formation as Cretaceous (Maastrichtian). South of Palmira, grey and black fine to medium-grained subrounded quartzites predominate with a feldspar proportion of no more than 10%. There are rare small, more feldspathic bands. The colour is derived from the presence of smoky or blue quartz. These are intercalated with black and grey slates. North of Palmira (Punín, Guamote, Cebadas) there are pale, pink, and purple (ferruginous) quartzites with intercalations of pale grey, green, and purple slates. Diagenetic concretions, some ferruginous, up to 10 cm in diameter, were noted by Cebadas and the Guamote River to the west.

Orthoconglomerates were noted in the pale facies in Punín, along the road south of Guamote, and along the Atapo River, east of Palmira. These carry subangular quartz clasts up to 1 cm wide with pale or dark shale flakes, and at Punín, small ferruginous clay balls.

This facies change of the Guamote division from north to south can be interpreted as a change from shallow to deeper waters. Thus, in the north, there was a deposition of conglomerates in a more oxygen-rich environment.

4.1.3 The Cebadas division comprises black slates with intercalations of fine to medium-grained black or grey quartzites.

4.1.4 Tectonism of the Guasuntos, Guamote, and Cebadas divisions: it is possible to speak of a single tectonic package manifested by subhorizontal tectonic structures from north to south.

North of Palmira, the first cleavage (S1) is found subparallel to the bedding (So) in a range from marked to weak. It is subparallel to movement zones between layers, with tectonic transport to the west. On the road south of Guamote, there are tectonic “pockets” of quartzites 20 m wide extended in an E-W direction.

South of Palmira, a second penetrative to subpenetrative cleavage (S2) is found in the slates, subparallel to So/S1, which also demonstrates tectonic transport toward the west.

The So/S1 plane north of Palmira, and the So/S1/S2 plane south of Palmira, has been affected by open to closed vertical folding with crenulation cleavage (S3) (in the slates) or jointing (in quartzites) with a strike around 70°, giving strong dips to So/S1 or So/S1/S2 in some sectors. This tectonic event (D3) is provisionally correlated with the reverse faulting that affects the “Río Zula” volcanics (Map 4) and, in this scheme, had nothing to do with the “collision tectonics” that formed S1 and S2.

4.2 The Peltetec fault

This is a fundamental structure. In the metamorphic basement, it represents the juxtaposition of the Cebadas or Guamote divisions and the Peltetec (ophiolitic) division. It also represents the tectonic change from subhorizontal cleavages in the west to subvertical cleavages in the east.

The Peltetec fault is also an important tectonic element in later history. The same line forms the Río Chambo fault where, through the Penipe window (Map 2), the Peltetec division is juxtaposed against Pleistocene volcanics. Further south, the fault line affects the “Yunguilla Formation” (Cañar geological sheet) and the Tarqui Formation; it is an important element that affects (and produces?) the Miocene Cuenca basin, and controls the volcanics of the Cordillera Real and the movement of the Inter-Andean graben.

4.3 The Peltetec division

This “ophiolitic” division was observed in 1986 in three sections and two more during this commission. It is already mapped from Penipe in the north to the Río Zula in the south. Further south, it is covered by sediments and volcanics of Cretaceous-Pleistocene age. In the five sections, it maintains a width of 1.5 to 2 km. In the Huarguallá section (Map 3), it is noted that the lithologies are in the form of tectonic slivers. The lithologies from west to east in each section are as follows:



Penipe (Map 2):	Serpentinites and ?gabbros?/black slates/black quartzites, metabasalts.
Peltetec (Alao) (Map 3):	Serpentinites/gabbros picrites/silicified rocks, metabasalts, quartzites/black slates.
Huarguallá (Map 3):	Blue quartz metagranitoid, serpentinites, gabbros, metabasalts, black slates, metabasalts, cherts/purple fine-grained sediments, metabasalts, cherts, etc., andesites, graywackes/black slates/sedimentary breccias, cherts/purple fine-grained sediments.
Guamote-Atillo road:	Metabasalts, silicified fine-grained sediments/cherts, blue quartz metagranitoid, cherts/black silicified sediments.
Río Zula (Map 4):	Silicified mélange, blue quartz metagranitoid, greywacke/mélange/sedimentary breccias/cherts, andesites, cherts.

With these details, it is noted that the oceanic crust portion (serpentinites, gabbros, metabasalts) is absent south of Huarguallá. However, there are other elements: mélange, blue quartz metagranitoid, and cherts (oceanic sediments) that remain to identify the division. Nevertheless, on future maps, it is probable that south of the Río Cebadas, the Peltetec division may be interpreted as part of the Maguazo division. Everything depends on the criteria used.

In the Peltetec division, a subvertical cleavage has been noted parallel to the movements that produce the tectonic slivers.

4.4 The Maguazo division

This division is distinguished by fine turbidites and metalavas, predominantly andesites. The division can be mapped from Penipe in the north to the Río Paute in the south.

There are excellent outcrops of the fine turbidites along the Alao, Huarguallá, and Paute valleys. It comprises hard massive banded rocks with the more psammitic sectors having a pale appearance and the more pelitic ones having a black appearance, normally with graded and cross-stratification (ripple marks). Apart from the turbidites and massive andesites, there are white/grey cherts in the Río Zula and Río Paute; black slates, siltstones, sedimentary breccias, fine tuffaceous rocks, and rare orthoquartzites and limestones. A thick band of pale limestone was mapped in the Río Zula (Map 4), and the turbidites to the east maintained thin bands (5 cm) of limestone. 50 m east of the Totorá Yacu Ravine (Río Paute), there are also limestones (dark). In the Río Jadan (tributary of the Río Paute), there are brecciated blocks of pink chert (tectonic mélange) and sedimentary-volcanic mélange.

The evaluation of the structure of the Maguazo division is strongly supported by the sedimentary structures in the turbidites, which provide the “younging” direction in the stratification. This had been confirmed by a syncline (D1) in the Río Maguazo (Map 3) previously identified by Dr. B. Marten of B.P. Minerals (personal communication). Similarly, a syncline (D1) would have been located in the Maguazo division of the Río Paute (Totorá Yacu Ravine) and it may be that they represent a single structure. Using this syncline in the section of Map 3, a Maguazo division with a stratigraphic column of more than 3 km in thickness can be postulated.

4.5 The San Antonio fault

In the Alao valley, there is a sharp change between the Maguazo division and the Alao-Paute division, both in composition and in metamorphic grade. In the Alao valley, this contact zone is marked by about 500 m of pink-coloured silicified rock, and this phenomenon has been noted on both sides of the valley (Map 3). Silica veins were noted crossing the schistosity of the metamorphic rocks as evidence of late silicification, possibly of the age of the Tarqui volcanics.

4.6 The Alao-Paute division

These rocks outcrop high in the Alao valley where most of the outcrops show “greenstones” and greenschists with a strong second cleavage (S2). They also outcrop east of Laguna Atillo (Litherland and Bermudez, 1986b). Along the Río Paute, the meta-andesites, tuffs, and agglomerates of this division are less metamorphosed and with a single subvertical cleavage (S1). Attempting to locate outcrops between Atillo and the Río Paute through the basement windows southwest of Cubillín Lagoon (Alausí geological sheet), only small boulders of feldspathic quartzites were found (Map 1).

4.7 The Guarumales division

We did not study this sector, but Map 1 demonstrates its projection.

4.8 Intrusive rocks

4.8.1 Blue quartz metagranitoid: the biotitic blue quartz metagranitoid, already known for its presence along the Baños front (Litherland, 1987), was detected within the Peltetec division by the Río Zula (Map 4), following its presence further north in the same division (Map 3).

4.8.2 Alao valley intrusive: near the town of San Antonio de Alao, a new intrusive of post-tectonic hornblende and biotite “tonalite” type was discovered with an andalusite aureole in the slates of the Maguazo division. In a certain sector of the intrusive (Map 3), there are blocks of blue quartz metagranitoid.

4.8.3 Minor intrusives: there are felsic intrusives in the Guamote division along the Río Zula (Map 4). These cut regional S1, but are cut by regional S2. Similar minor intrusions were seen along the Guamote-Macas section (Litherland and Bermudez, 1986b).



4.8.4 The Tampanchi mafic-ultramafic Complex: this complex is marked as “amphibolites” on the Cañar geological sheet. It comprises a 2 km section where medium to very coarse-grained black hornblendites outcrop (with crystals up to 6 cm long); gneissic amphibolites; friction serpentinites; hornblende rocks and amphibole asbestos; and gabbros, in some sectors of pegmatitic type. This complex is cut by mafic and granitoid dikes, and dioritic bodies. There is a subvertical penetrative cleavage with an Andean strike in the biotitic amphibolites, and some felsic dikes are strongly sheared. There is also a block containing pyroxene in thin section. The amphibolites are intercalated with the hornblendites.

This complex requires more studies to determine its geological environment vis-a-vis the “collision” divisions (Alao-Paute and Guarumales). There is little possibility that the Tampanchi Complex was another ophiolitic belt. There are many lithotypes and the intrusive-tectonic history is very complex.

4.9 Interpretation

The lithological belts already mapped and their different tectonic aspects support a continent-continent collision model:

- (1) The rocks of the Guasuntos, Guamote, and Cebadas divisions are continental metasediments. Their westward thrust tectonism supports the presence of the Chaucha-Arenillas continental plate below (Aspden and Litherland, 1987).
- (2) The Peltetec ophiolitic division is now a regional reality and can be interpreted as an extinct ocean: the suture.
- (3) The mapping of the Maguazo division from Penipe to the Río Paute is also impressive, showing andesites and fine turbidites of the forearc type, mixed in certain sectors with oceanic rocks such as cherts.
- (4) The Alao-Paute division, dominated by andesitic lavas, would be the island arc.
- (5) The identification of these units along 150 km of strike supports a right-angle collision. An oblique collision with sinistral or dextral tectonism would form tectonic lenses of the collisional elements.

5. POST-METAMORPHIC COMPLEX GEOLOGY

5.1 The “Macuchi Formation”

This has been noted in the western sectors on the geological sheets of Riobamba, Alausí, Cañar, and Azogues. French studies (Lebrat et al., 1986; Megard and Lebrat, 1987) indicate that these volcanic rocks should be divided between the Nono-Shobol arc (west of the Pallatanga suture) and the Celica Formation (east of the Pallatanga suture). It is possible then that the Macuchi rocks in Map 1 belong to the Celica Formation (Cretaceous); continental arc-type volcanics.

This commission has visited the outcrops of the “Macuchi Formation” and more sectors have been found along the Chambo River, east of Guasuntos, and to the NE of Azogues. From north to south, the sites are as follows:

5.1.1 Yaruquíes (south of Riobamba): these are massive green altered andesites without cleavage, exposed at the bottom of the ravine.

5.1.2 Río Chambo (south of Licto): here, volcanic/subvolcanic rocks of the green altered andesite and porphyry type outcrop (Map 3), which are not noted on the Riobamba geological sheet. It appears there is a transition to plutonic rocks (Licto-Pungalá granodiorite), which was noted cutting the volcanics (see 5.3). A subvertical jointing at 70° in the volcanics may be correlated to the D3 event in the metamorphic divisions of Cebadas, Guamote, and Guasuntos.

5.1.3 Columbe Valley (near Guamote): andesites and breccias outcrop with a faulted contact against the quartzites of the Guamote division. This fault is interpreted as the extension of the Ingapirca fault (Map 1).

5.1.4 East of Guasuntos: on the Alausí geological sheet, these volcanics are shown as intercalated with the metamorphic rocks (“Paute Series”). In reality, although the relationships between the units are close, they are tectonic and not stratigraphic. The volcanics (Map 4), fine felsic lavas, pale grey and pink, and porphyritic lavas, are massive and without deformation or metamorphism. Tectonic contacts in the field with the black slates of the Guasuntos division, which have two penetrative cleavages, are reverse faults, with a strike around 70 degrees, and with dips of 40-90 degrees. Thus, there are outcrops where the basement slates are structurally noted above the volcanics.

The reverse fault phase is tentatively correlated with the D3 event in the metamorphic rocks (open to tight vertical folds with a strike of 70°).

5.1.5 Río Silante (NE of Cañar): here the Ingapirca fault divides the volcanics (to the west) and the Guamote division (east) as in the Columbe valley (5.1.3). The volcanics are acid porphyries with a greenish alteration.



5.1.6 Reinterpretation of the relations between the Macuchi Formation and the “Paute Series” in the Cañar and Alausí sheets: Bristow et al. (1975) propose the correlation between the non-metamorphic Macuchi and Yunguilla Formations, respectively, with the “San Francisco” and “El Pan” metamorphic Formations of the “Paute Series”. The negation of this correlation comes from data from the Río Dudas (Aspden and Litherland, 1987) and the following:

- (a) On the road to the NE of Azogues, in a quarry at 17.1 km (7486-97040), there are amygdaloidal dacitic lavas without deformation or metamorphism, noted on the Azogues geological sheet as “Paute Series”.
- (b) At 17.9 km (7482-97045), these lavas are intercalated with non-metamorphosed tuffaceous rocks which correspond to the Yunguilla Formation.
- (c) Following this road to Taday, there are outcrops of both lithologies without regional metamorphism. To the east of Taday (7597-97083), there is another quarry with fresh volcanics. This entire section is designated as “Paute Series” on the Cañar geological sheet.
- (d) Following the same road to the east, there is a fault zone with phyllites and then at 7617-97089 fine meta-andesites with tectonic fabric and metamorphic minerals, followed by the Tampanchi ultramafic-mafic complex (4.8.5).

Thus, it is indicated that the meta-andesites of the Alao-Paute division, those outcropping at 7617-97089 and along the Paute River to the south, are overlain, with unconformity, by non-metamorphosed lavas of similar composition, intercalated at the base of the Yunguilla Formation, and Map 1 indicates the probable extension of this unit dominated by lavas.

To further support this interpretation, lavas intercalated with the Yunguilla Formation were noted in the San Pedro River, east of Cañar, that is, on the western side of the Yunguilla basin.

Regional evidence also supports the negation of the correlation of Bristow et al. (1975). The divisions of the “collision” belt south of the Zula River are covered by the Yunguilla Formation, which is essentially non-metamorphosed. This relationship is clear in the images.

5.2 The Yunguilla Formation

As written above, this Maastrichtian age unit is found with basal lavas. Further up there are tuffs, tuffaceous sandstones, and argillites. In the Dudas River there are turbidites (Aspden and Litherland, 1987). The Ingapirca Formation (Bristow et al., 1975) is now part of the Guamote division of the metamorphic complex (see 4.1.2).

5.3 Mesozoic? Plutons

The Licto-Pungalá granodiorites (Map 3) cut the volcanic/subvolcanic rocks in the Chambo River and appear to be their plutonic equivalents. This plutonic phase can be traced in the form of boulders in tributaries of the Cebadas River (Litherland and Bermúdez, 1986b) up to the Magtayán complex (Alausí geological sheet) and possibly as far as Amaluza (Paute River) (Map 1).

5.4 Cenozoic rocks

These comprise the dominantly continental volcanic units of the Palaeocene-Holocene that cover most of the area and which were not studied in detail. They also probably include the silica zone along the San Antonio fault (Maps 1 and 3). This silica zone could be due to hydrothermal solutions during the Tarqui volcanic event.

5.5 Post-Metamorphic Complex tectonism

This includes the following:

- (a) Opening of the Celica?-Yunguilla volcanic-sedimentary basin in Cretaceous times, controlled by fundamental faults of the collision zone (e.g., Peltetec fault).
- (b) Reverse faults, with a strike of 70° in the Cretaceous volcanics of the Zula River (Map 4), which possibly correspond to D₃ folding in the Guasuntos, Guamote, and Cebadas metamorphic divisions. These structures formed in the 'flat zone' and have not been noted to the east of the Peltetec fault ('standing zone').
- (c) Rejuvenation of the 'collision' faults during the Cenozoic Era. Thus, the Peltetec fault, the ancient suture, is marked by vertical spacing, especially noted in the Chambo River. Due to the Peltetec and San Antonio faults, the sediments and lavas of the Yunguilla Formation reach steep inclinations



6. MINING POTENTIAL

6.1 New mineralization sites

6.1.1 Polymetallics

- (a) Copper mineralization (malachite) was noted on joint surfaces in the Alao River intrusive (Map 3). In this valley and in Huarguallá there are many polymetallic mineralization sites (Map 3 and A. Hirtz, personal communication) including manganiferous deposits in the Maguazo division (A. Hirtz, personal communication), which could be derived from oceanic manganiferous sediments.
- (b) North of the Silante River (7381-97208) in a Macuchi? volcanic quarry there is a small zone with strong alteration and the possible presence of malachite.
- (c) In the San Pedro River (7392-97145), east of Cañar, there are quartz veins in the Guamote division that carry ferruginous mineralization with reddish and yellowish alterations. Further east (7416-97145), there is a small malachite mineralization associated with sediments/lavas of the Yunguilla Formation.
- (d) Near the Totorá Yacu creek (Paute River) (7417-96849) where the axial trace of the syncline passes through the Maguazo division, there is a small mineralization of sulphides and copper associated with cherts and turbidites, and quartz and calcite veins. It appears that this mineralization is of the 'stratabound' type because it appears in the same lithology on each flank of the syncline, 120 paces to the west and 180 paces to the east of the creek along the road.

6.1.2 Asbestos of a probably tremolitic type and formed from hornblende is found in the ultramafic rocks of the Tampanchi complex. Some samples have around 50% asbestos. However, the fibres are small (less than 1 cm), and tremolite asbestos has no commercial significance.

6.1.3 Phosphate? on the crossing of the Zula River there are thin "layers", up to 20 cm thick, of a reddish-brown clayey earth within the quartzites of the Guamote division (Map 4). They contain isolated quartz crystals up to 1 cm long and therefore could be an altered felsic dike. The possibility of phosphatic rock is doubtful.

6.1.4 Red jasper is found as small blocks in the Jadán River (tributary of the Paute River). It is an intense red coloured chert. It could be used in a small ornamental rock industry.

6.2 Regional mineral potential

Map 1, the new map of the sector, demonstrates that the lithological collision divisions are bounded by collision faults, which control subsequent geological events. Thus, the map opens new perspectives for mineral prospecting. Based on known mineral indicators, there appear to be three important ages of mineralization:

- (a) Pre-collision
- (b) Syn-collision
- (c) Post-collision, especially by the Tarqui Formation.

6.2.1 Pre- or syn-collision mineralization comprises syngenetic mineralization such as ophiolitic (Cr, Cu, Ni, Pt, Pd, Au, etc.), sedimentary (Mn), and volcanogenic polymetallic, and its redistribution during the collision process (tectonics). Regarding ophiolitic type mineralization, the Peltetec ophiolitic division is now delimited, and prospecting should concentrate north of the Cebadas River where elements of the oceanic crust outcrop. Small Cu mineralization has been noted in this division and there is a Ni and Cr geochemical anomaly in Peltetec, and 1 ppm Au in the Huarguallá serpentinite (Litherland, 1987). Other gold analyses are expected for this sector.

To prospect for sedimentary and volcanogenic mineralization, the Maguazo and Alao-Paute divisions are targeted. There are plenty of indications of polymetallic type mineralization in the Alao sector, including syntectonic mineralization along the Baños front (Litherland, 1987).

6.2.2 Post-collision mineralization: the Tarqui Formation represents volcanic deposits of Pleistocene age with epizonal type intrusives. In Alao, there is a post-tectonic silica zone along the San Antonio fault and along the same fault, in the Pilzhum Mine (Tarqui Formation), the mineralization is in silica veins (Bristow et al., 1975). It is possible that the San Bartolomé and Pilzhum polymetallic deposits, related to the Tarqui Formation, represent the remobilization through ancient collision faults of the pre- or syn-collision mineralization in the metamorphic rocks. Therefore, the collision faults are prospecting zones for both syn-collision mineralization in the Metamorphic Complex and post-collision mineralization within units such as the Tarqui Formation. Litherland (1987) noted the probability of syn-collision and post-collision mineralization (colonial silver mines in Altar) along the Baños front.

Silica rock samples from the San Antonio and Peltetec faults will be sent for gold analysis.

6.2.3 The Tampanchi ultramafic complex must be mapped in detail with its extension to the north and south. The ultramafic-mafic rocks, 2 km wide, and the intimate relations with acidic and dioritic phases indicate an environment suitable for the prospecting of metallic mineralization of various types of paragenesis.



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Dr. Martin Litherland

CORDILLERA REAL PROJECT

No. 0514

QUITO, FEBRUARY 01, 1988

TO : GERENTE TÉCNICO

FROM : ING. FRANCISCO VITERI and DR. JOHN ASPDEN

SUBJECT : Technical Report of the commission carried out from November 9 to December 4, 1987, to the provinces of Azuay and Morona Santiago

SUMMARY:

The work carried out during this commission was performed by two groups, the first led by Ing. Francisco Viteri and the second by Dr. John Aspden and Mr. Manuel Céleri, who completed the following traverses: Gima-Quebrada Osormana-Chigüinda-Gualaquiza; Gima-San Miguel de Cuyes-Nueva Tarqui; Sevilla de Oro-Río Negro-Copal-Méndez; Sevilla de Oro (old road)-Río Chorro Blanco, Tres Lagunas; La Merced-Río Collay-La Merced; Sta. Teresita-Caygual-Río Martirio and San Vicente-La Merced; all of these works are located within the metamorphic belt of the Cordillera Real.

The structural-geological study and the collection of petrographic and geochemical samples were carried out through geotraverses, mostly on foot.

The localities that are part of this study are high mountain range areas with an average altitude of 3700-4000 meters above sea level (mams), resulting in a cold paramo climate where access is difficult; the characteristic vegetation consists of *pajonales* (tussock grasslands) and small shrubs typical of paramo or cold climates.

Within the geological context of the adjacent cross-sections, specifically Gima-Chigüinda and Gima-Nueva Tarqui, it has been possible to continue with the definition or delimitation by belts, having from west to east the following: the metavolcanic belt corresponding to the one previously named Alao-Paute, followed by a sequence of tectonized contact rocks and intrusive rocks/foliated schistose gneiss with potassium feldspar megacrysts, then green schistose rocks very similar to those observed in the Paute-Méndez section (Technical Report, 1987). To the east, we have the semipelitic sequence consisting of phyllites with quartz concentrations, which indicate two cleavages and quartzites; finally, at the eastern end of the mountain range, it has been possible to observe and delimit with a good percentage of accuracy a contact between the semipelitic sequence and volcanic rocks that are quite silicified with pyrite in veinlets and disseminated. These volcanics probably correspond to the Chapiza Formation (Misahuallí Member).

Some contacts of these belts have been delimited by photogeology, see Map 1.



In Map 2, the Sevilla de Oro-Copal-Mendez geological cross-section is shown, where we have been able to define the geological sequence from west to east with the following belts: Alao-Paute metavolcanic and volcanic rocks, followed by a sequence of mylonitic rocks; further east, a belt of semipelitic rocks, mainly phyllites and quartzites, then volcanic and subvolcanic rocks possibly related to the Guarumales sequence; finally, toward the east, a sequence of marbles of possible Cretaceous age, culminating with the sedimentary sequence of the Hollín and Napo Formations. Petrographic samples were collected at 113 sampling points, along with 44 samples of fluvial sediments and heavy minerals in rivers and streams of interest.

The economic geology, mainly gold, is represented by the significant placer deposits of the Collay and Pilares rivers, with a good percentage of drainages existing where the content is lower.

1. INTRODUCTION

This report briefly summarizes several geological traverses carried out between November and December 1987 by the Cordillera Real Project (Southern sector). Details of the geological observations made, along with the location of collected rock samples and geochemical sediments, are presented in the attached maps (Maps 1 and 2). At the time of writing the report, thin sections and chemical analyses are not fully available; therefore, it is possible that the preliminary interpretations made here may be modified in the future when the aforementioned information becomes available.

As in other reports for this area, the boundaries presented in the traverse maps define major lithostratigraphic divisions (informal), but the age relationship between them is doubtful. Likewise, the cover of younger rocks, mainly volcanic (post-Cretaceous), is generally not shown; however, emphasis should be placed on the fact that these are often extensive, particularly to the west, as well as in the area east of Gima (Map 1).

2. GIMA-GUALAQUIZA

Details of the geological traverses carried out in this sector of the Cordillera Real are presented in Map 1. To maximize our efforts in this area, it was decided that we would split into two groups. Francisco Viteri completed the northern traverse from Gima to Gualaquiza, via Chigüinda and the Santa Bárbara River, while John Aspden carried out the traverse to the south via San Miguel de Cuyes and Nueva Tarqui.

It is possible to subdivide this part of the Cordillera into 4 major divisions, and we consider it important that similar divisions have been located both to the south and north of the area (see reports from previous commissions Gualaceo-Limón, Sigisig-Principal, and Oña-Yacuambí), suggesting that we are working with belts of regional significance.

2.1 Western gneissic/schistose belt

This belt is poorly exposed and is mostly covered under a thick and extensive layer of Pleistocene volcanics belonging to the Tarqui Formation. In places where these rocks are exposed, they are frequently strongly altered, and therefore it is difficult to obtain a real image of their exact nature. Regardless, this belt apparently consists mainly of gneisses and biotite $\pm$ muscovite schists that dip toward the west, some of which contain prominent quartz-feldspar megacrysts (2-3 cm). In addition to this, muscovite granite is present, which is more massive but generally foliated, and to the north (Osormana Creek), typical 'blue quartz' granites occur with large bluish-grey potassium feldspar megacrysts. Smaller amounts of quartzites have been observed within this belt, and it is possible that these represent a form of xenoliths within the granites.

The exposure levels do not allow for an unequivocal interpretation of this belt, but evidence found elsewhere would suggest that the gneisses and schists probably represent the most intensely deformed (sheared) sectors of the granite/granodiorite batholith. Data obtained during the Project's work indicate that the 'blue quartz' granites/granodiorites are almost certainly surface anatexis (S-type). The formation of these rocks is normally found associated with collision, and dating these granitoids remains a priority for the Project.

2.2 Semipelitic sequence

To the east, the western gneissic/schistose belt is replaced by a thick, monotonous sequence of semipelitic rocks, but these contact relationships between these two belts are not yet well defined, despite the fact that the 'blue quartz' granitoids mentioned are considered to intrude into the semipelitic sequence; however, it is probable that this contact has since been affected by major tectonism. The exposed sector of the semipelitic belt consists of a sequence with a strong to vertical dip. The S2 cleavage is dominant, and the main rock type is a low-grade graphite $\pm$ phyllite, although subordinate quartzites are also common. Quartz veins have been observed regularly. As observed in another sector of the Cordillera, the semipelitic belt contains little or no volcanic material and seems to have been derived exclusively from a continental source.

The semipelitic sequence disappears abruptly approximately half a kilometre east of Ganashuma, but the contact itself is not exposed; a similar case is found to the southeast of Chigüinda in the Guobical creek, where the change to volcanic rocks could be observed from this point.



2.3 Volcanic-subvolcanic belt

This belt occurs along the eastern margin of the Cordillera Real and is composed of a variably deformed sequence of dominant intermediate lavas and fine-grained dioritic/monzonitic intrusives. These rocks are considered to represent the subvolcanic equivalent of the lavas. Felsic tuffs (?) are also present to the west near Quebrada Honda, and silicification zones are common to the east of Chigüinda. The belt apparently contains little sedimentary material.

Cleavages, possibly related to shear zones, are variably developed, and as a result, the sequence includes both massive “non-metamorphic” rocks, apparently undeformed, and “greenschists”. Metamorphism is considered to be uniform and low-grade along this belt, and its effects manifest more obviously along shear zones.

The eastern margin of the volcanic belt could be considerably more complex than what is presented in Map 1, as blocks of cleaved sediments “similar to the Napo Formation” occur sporadically along the road east of the Río Amarillo. Based on evidence from the outcrops, it appears that the volcanic rocks extend eastward to the Río Bravo. The evidence that can be found in thin sections might lead us to resolve certain doubts, but it is very likely that detailed mapping will be necessary to define the exact nature of this boundary.

In regional terms, the volcanic/subvolcanic belt is of a probable Jurassic age and, as such, is considered to be related to the Misahuallí Member of the Chapiza Formation. But until it is confirmed that these data are reliable dates, this correlation can only be considered tentative.

2.4 Cretaceous sequence

To the south of Map No. 1 and east of the Río Bravo, there are quartzites that probably belong to the Hollín Formation and are exposed along the road to Nueva Tarqui. In Quebrada Vicente, the Napo and Hollín Formations outcrop in the form of a faulted contact, but exhibiting normal stratigraphic relationships in which the Hollín is underneath. On the eastern flank of Quebrada Vicente, felsic and siliceous lavas outcrop; contact relationships were not observed, but they are tentatively assigned to the Napo Formation.

Detailed subsequent mapping in Quebrada Vicente is worthwhile as this would help clarify structural relationships, especially those between the Napo Formation and the Hollín Formation, within the mountain front of the Cordillera Real.

2.5 Younger intrusive/volcanic rocks

To the west, felsic tuffs of the Tarqui Formation cover much of the Cordillera and Pullcu Urcu and Moriré, which form prominent hills, probably representing only two of the many Tarqui subvolcanic vents.

Blocks of younger felsic tuffs/porphyries are also present in the Altar River and the San Pablo River, which indicate that post-Cretaceous volcanism was not confined to the west.

A strongly altered hornblende/muscovite pluton of tonalitic-granodioritic composition is exposed along the road to San Miguel de Cuyes to the west of Morire. Similar but fresher blocks of this type are found in the Morire River. It is not deformed and therefore could be of a probable Tertiary age (Lower?).

2.6 Economic Geology

Analytical results of the collected geochemical samples are not available at the moment, but historical alluvial gold, which is still being panned today, is of considerable interest. In particular, several drainages from the western gneissic/schistose belt carry gold. Both the Sangurima River and the Santa Bárbara River, which is located immediately east of this belt, are historically famous and are mentioned in ancient Spanish mining records. Together, these occurrences form part of what we have informally named the western gold belt, a mineralized auriferous zone that could be traced from the Collay River in the north to the Shingata River/vein area in the south. The work scheduled for 1988 will study this belt in more detail to more precisely understand its metallogenesis.

According to local information, small amounts of gold were taken from the Altar River, but operations have already ceased in this area (Altar Mines).

To the east, gold was panned from Quebrada Honda, which mainly drains the volcanic/subvolcanic belt. Extensive work is being done in the Amarillo River, but this area was not visited during the present commission and its potential source is unknown.

3. SEVILLA DE ORO-COPAL

The results of this traverse, much of which follows a little-used path along the Negro River, are presented in Map 2. In addition to this, traverses were carried out in the Chorro Blanco River, which is a tributary of the Collay River in the south, in the Chorro Blanco River east of Santa Rosa, and in the area around La Merced.

Geologically, this part of the Cordillera Real is complex; at the moment, we cannot say if the different belts presented in Map 2 have regional significance; the description of each of these belts will be carried out from east to west.

3.1 Cretaceous Hollín and Napo Formations

These Formations were not studied in detail, but there are excellent outcrops of the Napo Formation in the Negro River immediately east of Copal, and several blocks of quartzites of the Hollín Formation were observed toward the east along the road leading to Bella Unión. No contacts were observed between these two Formations; consequently, the structural relationship in this area is unknown.



Outcrops of the Napo Formation were observed north of the Shiro River, where they consist of black phyllites with cleavage. Several blocks of lava and volcanic breccias are also present, which are often deformed and assumed to be derived from the volcanic/marble belt to the west. In general, the outcrops found along the Shiro River-Copal road are poor, but thin-section evidence indicates that greenish quartzites are present in the town of Copal and also to the south, where they contain clasts of black calcite crystals. In the field, these rocks were identified as “metavolcanics”, although they are now tentatively considered to belong to the Napo Formation (see samples CRFV-450 and CRFV-449).

In the Negro River, the “classic” Napo Formation is exposed under the bridge east of Copal. Here, the rocks are typically dark grey to black and consist of fine-grained, carbonaceous, and siliceous phyllites. The original bedding is still clearly visible, and the sequence is affected by tight vertical F2 kink folds with a slight horizontal plunge to the north. Irregular white calcite veinlets and stringers are common. Large blocks of volcanic breccia are also present at this point.

3.2 Volcanic and marble belt

Immediately south of the Shiro River, the road along the Negro River rises abruptly and there is a drastic change in the geology. Along this line, the Napo Formation disappears and is replaced to the west by a sequence of variably deformed metavolcanics, marbles, and minor pale-coloured phyllites. Thin-section evidence indicates that the metavolcanics were probably originally andesites. Chlorite and epidote, along with sericite, are the main metamorphic minerals, and their development appears to be closely controlled by cleavage. Matrix recrystallization is common and sporadically distributed, but most samples examined have a strong tectonic fabric. Original feldspathic andesite phenocrysts are widely preserved as “augens” in the form of lenses, and in some samples, primary (magmatic) hornblende is present.

The marbles present within this thin belt vary in colour from greyish-white to blue. Generally, they are relatively pure, but they commonly contain minor amounts of quartz, which could indicate a predominantly detrital origin. They are assumed to be interstratified with the volcanics and in some cases are strongly foliated.

Finer-grained, pale-coloured phyllites within this belt probably correspond to tuffs or tuffaceous sediments. These were observed mainly in the form of blocks, and some have F2 kink folds similar to those observed in the Napo Formation.



Structural measurements across this belt are strongly to moderately inclined with cleavages dipping to the west. The western boundary appears to be abrupt and is marked by a vertical zone of mylonitic metavolcanics which, despite the increase in tectonism, still contain remnants of their original feldspar phenocrysts.

The relationship between these rocks and the Napo Formation to the east is not yet known; however, it is possible that these are age equivalents. Alternatively, this belt could be considered as belonging to the Misahuallí Member of the Chapiza Formation.

3.3 Black phyllitic belt

This belt consists mainly of a monotonous sequence of black phyllites, but also includes a smaller amount of quartzites. The phyllites are often graphitic with a good proportion of pyrite; additionally, quartz veins are common throughout. The sequence is structurally presented with steep to vertical inclinations and has a penetrative S2 cleavage.

3.4 Greenschist belt

This belt consists of a variety of lithological types, being one of the main greenschist sequences, which were defined by hand specimens. It also includes phyllites and impure quartzites. Thin-section evidence indicates that the main metamorphic minerals are biotite, muscovite, chlorite, epidote, and plagioclase.

Most of the metavolcanics are extensively recrystallized and often carry actinolite and clinozoisite. It appears that this belt is of a slightly higher metamorphic grade compared to the meta-andesites found west of Copal.

The boundaries of this belt are not well-defined, particularly to the west, and this data could vary once we complete a more detailed examination of the thin sections.

3.5 Semipelitic belt and semischist zones

With the disappearance of the greenschists and continuing to the west, the main rock type found is dark to black in colour, consisting of graphitic phyllites and quartzose phyllites. These rocks are generally poorly exposed, hence along most of the Río Negro road that crosses the Cerro Negro porphyries, only a few outcrops were observed.

The western boundary and the southern extension of these rocks in the Río Collay area are problematic, and a more detailed geological mapping will be required to understand the structural complexities of this area.



To the south in the Collay River, mylonitic rocks are exposed in the sector south of the junction with the Chorro Blanco River; smaller amounts of gneissic “blue quartz” granite are present. Field relationships in this area suggest that the granite intrudes semipelitic rocks, which also occur in the Collay River and to the east in the Chorro Blanco River. In the lower part of the Chorro Blanco River, graphitic phyllites outcrop, but blocks of altered green metavolcanics were also observed. These latter rocks were not noted in situ, and in the upper parts, the lithology of the Chorro Blanco River consists exclusively of quartzose phyllites and quartzose semischists. These rocks have been affected by a later event of open folds (F3?), but as clearly deduced from Map 2, the main cleavage is generally flat to moderately inclined, and structurally this belt could belong to the northern extension of the “flat” semipelitic belt, which is crossed by the Gualaceo-Limón road.

Toward the north, in the lower parts of the Quebrada Esmeraldas, preliminary observations indicate the presence of greenschists and phyllites, but the apparent absence of the “flat belt” of quartzose semischists, which occurs to the south, is problematic. It is hoped that future traverses planned for this area will help us resolve this problem. In this context, it would be of interest to note that east of Santa Rosa in the upper part of the Chorro Blanco River, quartzose phyllites and quartzose semischists with westward dips are also present. Despite the structural dips to the north being somewhat steeper, these rocks are identical to those found to the south, and minor “Z” folds suggest they are related to eastward-verging overthrusts. To the north, the eastern boundary of this belt coincides with a marked photogeological lineament, which is presented on the Map as a line separating the semipelitic belt from the semischists to the west. While the true nature of this contact has yet to be proven, to the south the image of this line disappears, but the presence of mylonites and gneissic “blue quartz” granite in the Collay River could mark its continuation to the south.

3.6 Alao-Paute division

At this moment, we still do not have thin sections corresponding to the Alao-Paute sector; therefore, the identification of the different rock types is based on hand specimens.

The lithologies found in the Alao-Paute division are variable and include feldspathic phyllites, graphitic phyllites, smaller amounts of quartzites, and greenschists are common. Some of the greenschists, especially east of Santa Rosa, are massive and have been tentatively identified as calc-silicates (Xcs on Map 2), but in other sites, metavolcanics are common. To the east of Santa Rosa, the disappearance of typically altered Alao-Paute green rocks coincides with a marked photogeological characteristic presented in Map 2. The southern extension of this line is uncertain, and unfortunately, exposure levels were insufficient to establish the exact nature of this contact. Despite this, it is clear that structurally the Alao-Paute division overlies the semischist belt, and it is possible that these rocks are separated by a tectonic contact (thrust).

Toward the south, along the road leading from El Pan to La Merced, the Alao-Paute division consists mainly of strongly tectonized feldspathic phyllites, which have an early cleavage (S1?) with a relatively gentle westward dip. Evidence for subsequent tectonic movements in the area is provided by the presence of a strong S2 crenulation cleavage inclined to vertical.

3.7 Volcanic/intrusive rocks

The Cerro Negro porphyries are not deformed; they contain hornblende and biotite, and disseminated pyrite is common. Their eastern contact with the semipelites is exposed in the Domingullo River. Rounded blocks of a similar porphyry were noted in the Martirio River to the south, and it is therefore likely that the intrusion extends into this area.

Felsic volcanic/subvolcanic rocks are also present in the Pilares River near its junction with Quebrada Trenza. These rocks also intrude the semipelitic sequence and carry large xenoliths of graphitic phyllites.

Smaller amounts of "blue quartz" gneissic granites are present in the Collay River. Evidence from other sites indicates that these are S-type granites, probably generated during continent-continent collision episodes. To the northeast of Sevilla de Oro, highly altered outcrops of a coarse-grained leucocratic gneiss were observed, but its origin is unknown.

3.8 Economic geology

At the moment, geochemical analyses of the various samples are not available, but extensive work is being carried out in the Collay River in search of gold. All operations in this river are alluvial, and despite the area's long mining history, the source of the gold is still unknown. According to local inhabitants, small amounts of gold are panned in the Negro River east of Copal.

4. RECOMMENDATIONS

During 1988, the Collay River area will be visited, and in particular, more detailed fieldwork will be carried out in the Pilares River. The geochemical program will include not only fluvial sediments and panned concentrates but also a limited number of whole-rock samples that will be analyzed for gold.



5. CONCLUSIONS

Regarding the geology of the area covered by Map 2, it is obvious that several fundamental questions remain unanswered. In regional terms, the geology of the Cordillera Real south of Gualaceo-Limón could be subdivided into a series of largely informal lithostratigraphic divisions, as demonstrated, for example, by the Gima-Gualaquiza traverse (see also reports of previous traverses). Nevertheless, north of the Limón-Gualaceo road, these divisions are much more difficult to recognize, and apparently similar rocks occur throughout the length of the Cordillera. The pelitic and semipelitic Loja division, which occurs extensively to the south, disappears toward the north, and the nature of this change has not yet been explained. Likewise, the occurrence of metavolcanic rocks of apparently similar composition and a similar metamorphic grade (greenschists) in the Alao-Paute division to the west, on the eastern Andean slopes (west of Copal), and within the same Cordillera, is difficult to explain. Reliable radiometric dating might be required to decide whether or not we are working with rocks of different ages in this part of the Cordillera Real.

The western part of the area covered by Map 2 represents the continuation of the strike of the Baños front. It is now clear that the Baños front is not a single line but rather a complex tectonic zone, the effects of which could extend for several kilometres. To the south, including the Collay River basin, this belt is associated with widespread gold mineralization, but its apparent disappearance to the north has obvious economic implications.

Ing. Ramiro Bermúdez A.

Dr. Martin Litherland

CORDILLERA REAL PROJECT

ATTACH. Geological and petrographic-geochemical sampling map Sevilla de Oro-Méndez
Geological and petrographic-geochemical sampling map Gima-Nueva Tarqui
and Gima-Chigüinda

No. 4513

QUITO, SEPTEMBER 14, 1987

TO : GERENTE TÉCNICO

FROM : ING. FRANCISCO VITERI and DR. JOHN ASPDEN

SUBJECT : Technical Report of the commission carried out from August 6 to 26 of the current year, to the provinces of Azuay and Morona Santiago, Sigsig, Oña and Yacuambí cantons.

SUMMARY:

The works carried out in this commission were conducted through three geological traverses: the first from Oña, Loma Voladora, Yacuambí, Yantzaza; the second from Mina Peggy, Santa Bárbara River, ancient mines; and the third from Principal to Tres Lagunas. All these sections were performed within the metamorphic belt of the Cordillera Real.

The structural-geological study was carried out by means of traverses on foot, together with the compilation of field geological data; geochemical samples of stream sediments and heavy minerals were taken in the sectors of interest.

The localities that are part of the study of this commission are medium-high to high zones typical of the mountain range, where the dominant altitude is 3900 meters above sea level. The characteristic climate is cold *páramo* and the vegetation varies depending on its altitude.

Within the geological context, the research area exposes young volcanic rocks probably corresponding to the Tarqui Formation, whose age is Pleistocene, and the metamorphic complex consists of the Alao-Paute volcanic and metavolcanic belt in the western section, the Central belt and the semipelitic belt towards the east.

Economic geology can be described by the existence of zones of interest regarding gold mineralization.



1. GEOLOGY

1.1 Sigsig-Principal

1.1.1 Introduction

Preliminary work carried out south of Sigsig this year (see Sigsig-Mina Peggy report, February 1987) indicated that this area was likely very important for the regional interpretation of the metamorphic geology of the Cordillera Real. Furthermore, in this area, there is historical and current mining activity, offering a good opportunity to study occurrences of mineralization, especially gold, while simultaneously relating it to a defined geological environment.

As previously summarized (Litherland et al., 1987), the prior work conducted by the Cordillera Real Project has allowed us to divide the metamorphic geology of the main mountain range into several informal lithostratigraphic divisions, which we believe will provide us with the basis to understand the metallogenic history of the entire Cordillera.

East of Cuenca, the Cordillera Real consists of: to the west, a main volcano-sedimentary unit, which belongs to the Alao-Paute greenschists and the metasedimentary division of the western collisional belt; immediately east of this unit lies an important tectonic zone containing a mixture of different rock types that are often strongly deformed; further east, there is an extensive sequence of low-grade rocks belonging to the Loja semipelitic division (see Gualaceo-Limón report and Litherland et al., 1987).

1.1.2 Local geology

Details of the traverses carried out east of Principal and Sigsig are found on Map 1 (see also Sigsig-Chigüinda and Gualaceo-Limón reports).

As can be seen, we have distinguished three main belts, or lithostratigraphic/tectonic units. We believe the Western belt could be assigned to the Alao-Paute division and consists of greenschists and low-grade metasediments (mainly phyllites). Compared to the rocks outcropping to the east, the Alao-Paute sequence appeared relatively undeformed, but towards its eastern limit, particularly around Sigsig, mylonitic rocks are found exposed. Until then, despite having had the possibility of establishing precise age relationships for several metamorphic units represented in this area, we have included these mylonitic rocks within the Central tectonic zone.

As its name indicates, the tectonic belt is essentially a tectonic zone. It includes a variety of rocks, possibly of different ages and origins, which are found to be variably deformed, but in their entirety can be considered essentially mylonitic. The types of rocks present include meta-andesites and metatuffs containing chloritoid, which are massive but strongly foliated; probable agglomerates that have been tectonically disrupted; and metasediments that also have a strong tectonic fabric and are often quite silicified. Furthermore, this belt is characterized by the presence of biotitic granitoids with blue quartz, often intensely sheared, which contain late megacrystals of potassium feldspar. Augen-textured gneiss and silicified schists, the latter sometimes containing pale blue quartz in the form of eyes (augen), are relatively common and are considered products of the tectonic processes that have affected the 'blue quartz' granitoids.

As mentioned above, in the west the belt includes rocks resembling those of the Alao-Paute division, while to the east it contains rocks that are lithologically similar to the semipelites of the Loja division. Thus, it is possible that these belts simply represent the tectonic transition between the Loja and Alao-Paute divisions and that the blue quartz granitoids are related to the collision of these two units. Although this is an attractive hypothesis, the fact that biotite (and not muscovite) is the main 'mafic' mineral within the granitoids, and that these rocks (here and in other sites in Ecuador, see also the Oña-Yantzaza traverse in this report) are probably granitoids (as opposed to true granites), could be presented as arguments against this interpretation.

Structural readings in the tectonic belt are inconsistent. Strikes are approximately NE-SW and dips vary from steep to nearly vertical to the NW.

To the east of this belt, the metamorphic rocks consist of low-grade semipelites of the Loja division and the boundary shown on Map 1 corresponds to the appearance of a 'flat' zone that seems to characterize the western margin of the Loja division through the Cordillera Real. The precise structural relationship between this 'flat' belt and the generally steep tectonic zone to the west is not clear at the moment, but planned future geological traverses would help us resolve these problems.

1.1.3 Economic Geology

Mineralization occurs extensively in this area; in particular, alluvial gold has been worked since colonial times. Unfortunately, the origin of the mineralization is unknown, but it could mean that felsic/acid intrusions, which probably belong to the Pleistocene Tarqui Formation, are common throughout the area. During the present study, these rocks have not been mapped in detail, but it is probable that pre-existing fractures, particularly within the tectonic belt, could have aided in the emplacement of the Tarqui Formation rocks and also served as an effective pumping system for the circulation of associated hydrothermal solutions.



1.1.4 Peggy Mine

Polymetallic mineralization (Ag, Cu, Pb, Zn) is located in late veins that cut the sheared 'blue quartz' granitoid. Several younger intrusives, including breccias believed to belong to the Tarqui Formation, are present in the Santa Bárbara River sector. Alluvial tin has also been panned from the streams around the Peggy Mine, and this probably relates to quartz-tourmaline rock samples that have been found along the road over the main mine area.

It is disappointing to see that, despite the considerable amount of work carried out by private companies in the Peggy area, we have been able to obtain very little information about this in the INEMIN central archive.

1.1.5 Río Santa Bárbara

This area was visited during the present study, and we can confirm that the entire sector contains gold. Extensive small-scale alluvial gold operations exist along the Santa Bárbara River, and according to local information, there is an abandoned tunnel on the Ayllón River approximately 1 km north of its junction with the Santa Bárbara River.

According to our guide, the mine is set in rock and the gold is located in a series of horizontal quartz veins, but unfortunately, it was not possible to locate the tunnel entrance. Despite this, we accept the information because, according to our own geological observations, this area is located in the 'flat belt' which, as mentioned before, characterizes the western margin of the Loja semipelitic division.

Upon our return to Quito, we hoped to check the details of this mine in the INEMIN central archive, but so far it has not been possible for us to obtain information concerning this operation.

1.1.6 Principal area

To the south and east of Principal, in the Shio River and its tributaries, gold is extensively worked by local inhabitants. These rivers mainly drain the tectonic belt, but it is possible that the Huigra River, which according to our guides contains the richest deposits, could in part drain the 'flat belt' of the Loja semipelitic division. Extensive small-scale alluvial gold works are present in the Shio River and, according to the inhabitants of the sector, gold is often found within quartz veins. As in the case of the Sigsig-Peggy Mine area, young felsic intrusives are common within the tectonic zone east of Principal and extensive silicification exists. At the junction of the Burro Playa River and the Minas River, there is the prominent Loma Fasañán Cari, which, although not visited during the present commission, has the typical shape of a volcanic vent.

1.1.7 Regional significance and recommendations

The areas of Sigsig and Principal form only a part of what we now believe is a regional gold belt within the Cordillera Real. As shown on Map 1, along the strike to the north is the Collay mining area (Sevilla de Oro), while to the south, among other zones, are the rivers containing gold known as Sangurima and Santa Bárbara. It is probable that, towards the south, this belt includes the famous Shincata mines, located east of Cochapata.

These gold areas were previously considered as isolated occurrences, but the data available at the moment, although preliminary, suggest that a close relationship exists between this mineralization and the basement geology of the Cordillera Real. Despite the fact that, as stated before, the age of mineralization is unknown, in each locality with gold content we have seen young felsic volcanics and intrusives, which probably belong to the Pleistocene Tarqui Formation and are quite common. A tentative hypothesis to explain the occurrence of the gold mineralization would be that it is related to the Tarqui event, but concentrated along pre-existing zones of tectonic weakness and fractures within the older metamorphic rocks. In the case of the Loja semipelitic division and the reported occurrence of gold in horizontal quartz veins, this would appear to be more closely related to the tectonic event that produced the 'flat belt'.

Obviously, many more works must be carried out to be able to answer the fundamental questions related to the gold mineralization of this belt. Future studies, particularly in the Shio River basin, offer a good possibility of resolving many of the most outstanding geological problems and in particular the age and origin of the gold mineralization. Any follow-up study in this area should not only include detailed mapping, especially of the stream sections, but should also involve a sampling program of stream and heavy sediments. It will also be necessary to collect whole rocks and small samples in a systematic way, as there is a high probability that gold may be present not only in quartz veins but also occurs as disseminations both within the 'metamorphic' rocks of the tectonic zone and in the younger Tarqui Formation.

1.2 Oña-Yacuambí-Yantzaza

Details of this traverse are presented on Map 2. Basically, the geology through this sector of the Cordillera Real is relatively simple and could be divided into three different belts. From west to east (excluding the younger volcanic cover), we have: the Tres Lagunas pluton, the semipelitic rocks of the Loja division, and the Zamora intrusive and volcanic complexes.

1.2.1 Tres Lagunas pluton

This pluton was first named by Kennerley et al. (1973) as a result of the 1:100000 scale geological mapping of the Saraguro Sheet (Sheet 55). According to these works, the pluton is of metasomatic origin and along its northwestern margin the country rocks consist of gneisses.



Anyway, as a contrast, our interpretation is that this is essentially an intrusive body and that the gneisses represent zones of intense shearing within the pluton. In the vicinity of the Negro River, we saw no evidence to support the existence of a separate gneissic unit. Likewise, the basement rocks presented in the Saraguro sheet at 1:100000 scale, which follows the Negro River/Cachihuaicu River, is probably incorrect, since at its junction with the Conventillos River, young volcanic rocks are exposed.

Unfortunately, the western limit of the Tres Lagunas pluton is covered by younger volcanic rocks, which have not been mapped in detail, but according to Kennerley et al. (1973), these belong to the Pleistocene Tarqui Formation, which consists mainly of felsic and/or acidic tuffs and lavas.

Detailed petrographic studies of the Tres Lagunas pluton have yet to be completed, but its composition appears to be quite uniform and is probably a granodiorite. The only mafic mineral found in collected specimens was biotite, and throughout the pluton, many late grey-bluish potassium feldspar megacrystals are found, one of which measured 14×5 cm. The early cream-white plagioclases that appear are small (approx. 1 cm) in the form of equidimensional euhedral to subhedral crystals, but in one sample, a cream-white feldspar rim was observed around a late potassium feldspar megacrystal.

The pluton is cut by numerous mylonitic shear zones, and the transition between undeformed intrusives and 'gneisses' associated with these shear zones could be demonstrated in a convincing manner in the field. The gneissic rocks also contain quartz-feldspar in the form of augen (eyes) and in some cases undeformed late potassium feldspar megacrystals, which can occasionally be found cutting the foliation. Based on these observations, we conclude that the megacrystals are of both syn- and post-tectonic origin.

On cut surfaces, it is observed that the potassium feldspar megacrystals replace and in some cases surround the early plagioclase crystals.

Quartz veins occur throughout the pluton but appear to be more common near and within the shear zones. Xenoliths include sedimentary types (quartzites) and greenschists of a probable igneous/volcanic origin. The shear zones are subparallel and have an approximate strike of 50 degrees with constant steep dips to the southeast.

In addition to the characteristics described above, some samples also contain pale-blue quartz. Despite this, it is not universally present in the Tres Lagunas pluton in another sector of the Cordillera Real. The blue quartz appears to characterize the belt of highly tectonized rocks located immediately east of the western collisional sequence. At the moment, the origin and affinities of these rocks are unknown, but they include a lineage of variably deformed granitoids, which in a characteristic way have late potassium feldspar megacrystals that often bear blue quartz.

The present traverse confirms the extension of this belt in the southern sector of the Cordillera Real, and dating these intrusions will be an important priority before a complete understanding of the regional geology of the Cordillera Real is achieved. As stated in previous reports of the Cordillera Real Project (see also Sigsig and Principal traverses in this report), these 'blue quartz' granitoids are frequently associated with mineralized areas and in particular with polymetallic and gold-bearing zones, where they are cut by younger felsic intrusives and by volcanics. Potassium-Argon dates, preferably for the Tres Lagunas pluton, will need to be confirmed for better work, which is planned for early 1988 as part of the second geochronological program.

1.2.2 Semipelites of the Loja division

Approximately 1 km west of Tignas (Map 2), cleaved rocks belonging to the Loja semipelitic division are exposed. These low-grade metamorphic rocks consist of a monotonous sequence of graphitic phyllites, quartzose phyllites, impure quartzites, and quartzites. The Loja division forms an important element of the metamorphic geology through the Cordillera Real south of Cuenca (see report of previous traverses), but the age of these rocks, although assumed to be Lower Paleozoic, is not confirmed.

Along the western margin of this belt, near the Tres Lagunas pluton, structural dips are tight?, but east of Tignas these become steeper and a penetrative S2 cleavage is frequently clearly visible. Insufficient detailed work has been carried out to allow us to make a reliable structural interpretation of this belt, but overthrusting to the west and tight to isoclinally folded in the east could be in agreement with current, albeit limited, field observations.

West of the Tutupali River, strikes are generally NE-SW and therefore are slightly oblique to the regional structural grades of the Cordillera. To the east, the semipelites are clearly intruded by the 'Zamora Complex,' with hornfels and silicification being common near the contacts. Clear intrusive relationships were not seen to the west, but we assume that the semipelites are also intruded by the Tres Lagunas pluton.

1.2.3 Zamora intrusive and volcanic complex

To the east of the semipelites, the geology consists essentially of an undeformed igneous complex. These complexes have not been mapped in detail, but the main plutonic phase consists of tonalite/monzonite containing hornblende-rich xenoliths. The tonalite generally contains both hornblende and biotite and is medium-grained. More leucocratic varieties rich in quartz are also present, but these transition into the more common tonalites and are considered to belong to the same intrusive phase. The volcanic and subvolcanic rocks present a variety of compositions; andesites, hornblende andesites, felsites, dacites, porphyritic feldspathic lavas, and volcanic breccias have been identified in collected specimens.



Several intrusive and volcanic rocks have been previously collected in this area to conduct dating studies using both the Rubidium-Strontium and Potassium-Argon methods, but at the moment we do not have secure evidence regarding the age of this complex. We now consider that the entire sequence represents a single igneous complex of similar age. Based on the collection of plutonic rocks carried out in this area and in the Zamora Batholith to the east, we would tentatively suggest that these rocks belong to the same event, and we also believe that the Zamora Batholith is actually more extensive than previously recognized. Confirmation of this hypothesis will, of course, have to wait for the results of the first part of the geochronological program, but in any case, in terms of regional geology, the location of the Sub-Andean tectonic front in the present area is a problem.

It should be made clear that the outcrops of the Zamora igneous complex between La Paz and Yantzaza are not continuous; we saw no evidence of the principal shearing or deformation such as what we would expect to find associated with the regional tectonic front, and its position in the area is still not clear.

1.2.4 Economic Geology

The association between Tres Lagunas-type plutons with both polymetallic and gold mineralization elsewhere in the Cordillera Real has already been mentioned. Regarding this, we believe that the Zamora igneous complex has high mining potential. Silicification zones are relatively common and are particularly found associated with subvolcanic complexes generally of felsic to acidic composition. Gold was panned from several streams that drain the Zamora complex and has also been panned by local inhabitants from parts of the Tutupali River. Float samples of magnetite and hornfels rich in pyrite were noted in seven areas, but particularly in the Cambana River and immediately downstream in the main Yacuambí River.

Sulphide-rich hornfels occur in outcrops east of the junction of the Ingenio River with the Yacuambí River, approximately 1.5 km south of Yacuambí; pyrite is generally a common constituent within the hornfels throughout the area. Similar sulphides are well-developed along the fault that presents a 1-meter-wide mineralization zone, which cuts the intrusive along the main road approximately half a kilometre north of the Curishpe Creek. Several large rocks and small samples have been collected in the Zamora complex, but at the time of writing this report, the results are not available. It is of possible interest to note that if this complex actually represents the western continuation of the Zamora Batholith, then it could have great potential for gold exploration. Although skarns have not been found, gold-bearing volcanics are known in the Nambija area, and at the moment, we consider that there is a high opportunity to find epithermal gold mineralization associated with the subvolcanic and volcanic complexes described individually.

Ing. Francisco Viteri S.

Dr. John Aspden

CORDILLERA REAL PROJECT

No. 2078

QUITO, APRIL 13, 1988

TO : GERENTE TÉCNICO

FROM : ING. FRANCISCO VITERI and DR. JOHN ASPDEN

SUBJECT : Technical Report of the commission carried out from February 4 to 26, 1988, in the southern sector of the Cordillera Real

1. INTRODUCTION

The geological field works carried out during this commission are located within the metamorphic belt of the Cordillera Real, in which the following traverses were performed:

Santa Teresita-Río Arenillas	(Map No. 1)
Laguna Maylas-La Merced	(Map No. 1)
Principal-Río de la Burra Playa	(Map No. 1)
New road between Loja-Saraguro	(Map No. 2)
Loja-Malacatos basin-Quilanga	(Map No. 3)
Valladolid-Porvenir	(Map No. 4)
Chito-La Cruz	(Map No. 5)

The structural-geological study and the collection of petrographic and geochemical samples were mostly carried out on foot and on second-order roads; the localities belonging to this study are partly high mountain range zones, with predominant altitudes of 3000-3600 meters above sea level, as a result of which the typical vegetation consists of grasslands (pajonales) and small shrubs, and the climate is cold páramo, as well as low zones such as the Loja, Malacatos, and Zumba basins.



Within the geological context, in each of the sections there is a predominance of metamorphic rocks, plutonic rocks, recent volcanic rocks, and sedimentary rocks of the tertiary basins; regarding economic geology, there are good indications of metallic minerals, especially gold, and non-metallics (limestones).

For a clearer explanation of the different names and informal lithostratigraphic divisions used in this report, the reader should refer to the Annual Reports of the Cordillera Real Project for the years 1987 and 1988.

2. GEOLOGY

2.1 Introduction

This report summarizes the geological traverses carried out during the month of February of the current year by the Cordillera Real Project (southern sector). Details of geological observations made together with the location of petrographic and sediment samples collected are presented in the maps attached to this report. It is necessary to indicate that at the time of making this technical report, thin sections or geochemical analysis results are not available; therefore, it is possible that the interpretations made on the map may have some variation in the future when the respective microscopic analysis is obtained.

This report, like others, indicates the description by traverse belts, which define major lithostratigraphic divisions, but of still doubtful ages, presenting difficulty in interpretation in zones of recent volcanic cover or in zones of post-Cretaceous plutonic rocks that are often extensive in dimension.

2.2 Santa Teresita-Río Arenillas geological section

This traverse was carried out from the town of Santa Teresita, then following upstream through the Esmeraldas Creek and finally taking the Arenillas River, along the left bank, to very near the Cruzado River. This sector is of considerable complexity for making a regional geological interpretation; thus, this traverse has been divided into the following provisional belts:

2.2.1 Western belt: Alao-Paute metavolcanics

From Santa Teresita to the Ramos Lomo Creek, there is a sequence of poorly exposed green metavolcanics belonging to the Alao-Paute belt, partly covered by recent Pleistocene volcanic rocks of the Tarqui Formation. This sequence of rocks consists mainly of massive to schistose green rocks; in some cases, these green rocks contain a high percentage of quartz. The tectonism of these rocks increases progressively towards the east; the cleavage in these zones has Cordillera strikes and medium dips to the west, as can be seen on Geological Map No. 1.

2.2.2 Semipelitic and green rock zone

From the previous point, up to more or less a good part of the Esmeraldas Creek, a change in lithology has been observed, first with the existence of mylonitic rocks at the junction of the Huabisay Creek and the Collay River, where excellent outcrops of green rocks with significant tectonism are exposed; from which towards the east we can observe the existence of quartzites and black phyllites, the former being grey and the latter appearing graphitic with a high tectonic grade, such that we can see that these rocks appear folded in various directions and in some cases “S” shaped folds (?) can be seen.

There are very good outcrops of mylonites as we had already stated, at the junction of the Huabisay Creek with the Paute River (previous reports, 1987) and there is also a quartzose mylonite at the junction of the Martirio and Esmeraldas rivers (CRFV-378 and CRFV-552). The tectonism is strong, such that there is no defined orientation for the direction of foliation in what corresponds to the eastern sector.

2.2.3 Semipelitic belt

In the highest part of the mountain range, there are no good exposed outcrops, having quite a bit of recent volcanic cover which has prevented obtaining structural data and their respective tectonic correlation, such that since the headwaters of the Esmeraldas Creek and the San Juan River, the semipelitic belt has been considered in the first instance, the same which is directly related to the Loja division from a regional point of view.

The crossing from the Esmeraldas Creek to the Cruzado River, following the left bank of the Arenillas River, was carried out by opening a trail and uncovering small outcrops in some cases, which made it difficult to have more geological-structural information.

The lithology in this sector consists of impure quartzites and graphitic phyllites, with small outcrops of green phyllites and limestone levels. At the junction of the Cruzado with the Arenillas, there is a green rock (CRFV-521), the same which could be a green schist with quartz.

This sequence is marked by an S₁ cleavage with steep dips and Cordillera strikes (approximately N-S). Crenulation cleavages can be seen in the Huagrarancha Creek (a small tributary of the Esmeraldas Creek), where there is also the presence of sericite, being the only sector where a well-developed second cleavage could be seen. It is important to indicate that the boulders of most existing rivers and creeks have been studied, and boulders of mylonites could be observed in the Tingas River.



2.2.4 Volcanic-intrusive rocks

The existence of rolled blocks in the Collay and Martirio rivers of recent volcanic and intrusive rocks was due to the existence of good outcrops at Cerro Caricollay; these rocks are very similar to those of Cerro Negro. These involve a porphyry with hornblende and biotite (monzonite), where it is common to find disseminated pyrite. This intrusive appears undeformed; the contact of this porphyry has been delimited based on photogeology.

There also exist recent volcanic rocks, mainly tuffs, which are covering a good part of the western sectors; these volcanics belong to the Tarqui Formation.

2.3 Laguna Maylas-La Merced and Principal-Río de la Burra Playa

To carry out this traverse in the case of Maylas-La Merced, it was conducted following downstream through the Culebrillas Chico River, then reaching the junction of the Pilares River; from this point, it was not possible to continue along the river course due to climatic factors, such that from the junction of the Pilares with the Chorro Blanco, it continued to reach the previous point. For the geological study of the Burra Playa River, it started from the town of Principal toward the Huigra Creek; from this point, it was possible to follow along the right bank of the Burra Playa River to its headwaters, distinguishing the following lithostratigraphic divisions (Map No. 1):

2.3.1 Alao-Paute division

At the moment, thin sections of these sectors are not available; it is for this reason that the identification of the rocks was macroscopic.

In the Trenza Creek, outcrops of green schists and green phyllites are exposed, and occasionally quartzites; in some cases, the phyllite is quite siliceous. In contrast, the schists and quartzites appear massive. Further south in the Shio River and at the confluence of the Burra Playa and Minas rivers, massive metavolcanics with light cleavages could be observed. In general, the cleavage in these zones has Cordillera strikes with relatively soft westward dips; in these zones, crenulation cleavages could not be observed.

2.3.2 Tectonic Zone (granite-gneiss-semipelites)

These rocks are not well exposed due to strong weathering and recent volcanic cover; this prevents having a clearer idea regarding the study areas. In places where outcrops of rocks exist, these are strongly altered and sometimes intercalated with semipelitic rocks and green rocks (metavolcanics). In any case, this belt consists of gneisses with biotite with or without muscovite, some of which contain feldspar phenocrysts of 2-3 cm; for example, an outcrop northeast of Laguna Maylas where quartz-feldspar augens could be seen. Massive and foliated muscovite granite could also be seen as in the case of the outcrop of the Pilares River at the junction with the Culebrillas.

We could also observe this granite-gneiss with blue quartz, although it was quite weathered on the road leading to the Burra Playa River. If we take into account that in the previous commission a similar body was found in the northern part - that is, in the Collay River - these data have allowed for a clear idea of the existence of this belt, which is currently termed the Tres Lagunas Suite granites.

However, these rock belts indicate sectors of a high degree of tectonism; these rocks have been intensely deformed from the granitic/granodioritic batholith.

The formation of these rocks is normally associated with a collision, being of much interest to the Project. As in the previous belt, the strike of the schistosity of these granites is approximately N-S, having moderately strong westward dips.

Within this belt, semipelitic rocks can be observed, which in certain cases indicate two deformations; the regional implication of this sequence of granitoids is explained later in this report.

2.3.3 Semipelitic belt

To the east of the granite-gneiss belt lies the monotonous sequence of semipelitic rocks, and in some sectors green rocks, which could be metavolcanics.

The sector exposed from this belt consists of a sequence of medium- to fine-grained quartzites, white and in some cases grey, as well as phyllites that may be feldspathic, graphitic, or quartzose. North of Laguna Maylas, a quartzite sequence with calcite levels (CRFV-557) exists; additionally, within this belt, quartz in the form of veins could be observed.

There are places, such as the headwaters of the Arenillas River, where green phyllites and metavolcanics exist alongside quartzites and graphitic phyllites that could be derived from a continental sequence.

In the exposed sectors of this belt, the sequence has Cordillera strikes with eastward dips; the S2 cleavage is dominant and well-developed, especially in the phyllites. Further east, the sequence becomes horizontal and with soft dips.

2.3.4 Volcanic rocks

The existence of volcanic rocks in the Culebrillas River and the Pilares River (in the form of columns) is dominant in the section carried out through the Pilares River, with few outcrops of metamorphic rocks existing.

This sequence involves felsic and undeformed volcanic rocks, which in some cases contain disseminated pyrite.



2.3.5 Economic Geology

Gold has been panned in most of the existing creeks and rivers in each of the crossings, finding good indications of gold in a tributary of the Esmeraldas Creek, in the Arenillas River, Collay River (at the junction of the Pilares and Collay rivers), as well as in the lower part of the Trenza Creek. Additionally, there are ancient works that are currently being reactivated in the Culebrillas Chico River. Panning has been conducted at the headwaters of the Burra Playa River without positive results; in any case, according to information from the inhabitants of the town of Principal, mining works are being carried out in the Burra Playa River very close to the junction with the Minas River.

Up to the moment, the origin of the gold in the Collay River remains in doubt; for this reason, in the future, sampling of stream and heavy sediments will be carried out to clarify the idea of its origin.

The existence of pyrite indications is also important, as in the case of the junction of the Culebrillas rivers.

2.3.6 Conclusions

The geology in the northern part of Map No. 1, attached to this report, is quite complex; it is for this reason that a greater detailed geological study and the respective study of thin sections are necessary to thus define zones or lithostratigraphic belts to subsequently have a regional concept.

2.4 New road between Loja-Saraguro (San Lucas)

In this section, all exposed outcrops along the recently opened road between San Lucas, which is located south of Saraguro, and Loja were examined.

At the moment, the topographic maps that should show the exact location of the new road are not available, and it is emphasized that the road line on Map No. 2 is only approximate. In general, outcrops of metamorphic rocks are sporadic, but as will be explained later, the genesis of the area could have important regional implications.

2.4.1 Geology

Toward the western margin of the Loja basin, relicts of semipelitic rocks are found exposed, the same which belong to the Loja division (see Project reports, 1987). Toward the west, however, these are found replaced by biotitic granite gneisses with or without muscovite, medium-grained and strongly foliated. Dark-coloured quartz-feldspar schists rich in biotite are also present; the contacts between the low-grade Loja division and the higher-grade gneissic rocks are not found exposed, but in both cases, the structural readings are somewhat anomalous as they are somewhat oblique in relation to the normal strike of the Cordillera.



The western limit of the gneisses, in the area of Cachipamba Creek, probably corresponds to a main fault associated with extensive shearing and silicification. To the northwest of Cachipamba Creek, the exposures along the road consist of weathered volcanic rocks of the Palaeocene Sacapalca Formation (Loja Geological Sheet, No. 56), and toward the north, the road crosses part of the San Lucas pluton, which has been dated by several researchers giving ages of 53 to 66 Ma (data summarized in the Annual Reports of 1987 and 1988).

To the east and north of Santiago, the new road follows the contact between the San Lucas pluton and what are assumed to be its related volcanics, of which both are probably equivalent in age to the Sacapalca Formation.

To the northwest of San Lucas, in the Gulag and Purón Creeks, and to the west of the San Lucas pluton, the presence of low-grade semipelitic rocks has been confirmed, and these can be correlated with similar lithologies exposed to the north along the main road leading to Saraguro (see the 1986 Saraguro-Loja traverse report).

2.4.2 Regional considerations

The gneisses exposed along the new road to Loja are similar to those occurring in the area near Solamar (see the 1986 Saraguro-Loja traverse report).

In other sectors, the gneisses of the Cordillera belong to the Tres Lagunas Suite (see the 1988 Cordillera Real Project Annual Report) and are widely disseminated. At the moment, the “Loja gneisses” are tentatively assigned to this suite. It should be pointed out, however, that certain characteristics of the Tres Lagunas suite have yet to be identified in the “Loja gneisses”, and the possibility that these rocks may represent a pre-Loja division basement should not be ruled out.

In our previous traverse along the old Saraguro-Loja road, the low-grade pelitic and graphitic phyllites occurring north of San Lucas were considered part of the Loja division (see the 1987 Cordillera Real Project Annual Report). As shown on Map No. 2, the western limit of the “Loja gneisses” corresponds to a fault, and the NNE extension of this line is represented by a strong geological photo-lineament. If, as is suspected, this line has regional significance and actually defines the western margin of the Loja division and/or the Tres Lagunas suite, then in regional terms it would correspond to the Baños front. The metamorphic rocks found to the west of this line, that is, those north of San Lucas, should therefore correspond to the Alao-Paute division.

More detailed work will be required to confirm this possibility. It will also be necessary to carry out field checks and subsequent mapping to discover the true nature of the “Loja gneisses” and, in particular, to study their contact relationship with the Loja division, which in other places is found intruded by the Tres Lagunas suite.



2.5 Loja-Malacatos-Quilanga basin

As part of our research program on the nature of the metamorphic rocks of the Cordillera Real, fast field surveys were carried out along several secondary roads that exist in the area of the Malacatos basin.

Based on previous geological traverses, it is considered that part of the Cordillera Real could be composed of semipelitic rocks and low-grade pelites of the Loja division (see Annual Report of the Cordillera Real Project, 1987), and as can be seen, starting from map No. 3, these types of rocks are certainly dominant.

However, several bodies of biotitic orthogneiss with or without muscovite are also present, such as for example to the north of the Cordillera where very similar orthogneisses occur (see previous reports of traverses carried out by the Project) and there is very little doubt that the gneisses of the Malacatos basin area represent the southward continuation of this same belt. This set of plutons, which are frequently found intensely deformed, are referred to as the Tres Lagunas suite (see Annual Report of the Cordillera Real Project, 1988) and they are intruding and are therefore posterior to the Loja division. Evidence from thin sections and preliminary Sr-isotope data obtained in the Tres Lagunas unit indicate that these plutons are “S-type” granites and were derived from the melting of the continental crust.

The significance of said granitoid of the Cordillera Real of Ecuador is twofold:

In the first place, in other places in the world, “S-type” granitoids are considered to be related to collision and are thought to be formed by anatexis of predominantly continental material, in the deepest levels of thick crustal accumulations; therefore, the presence of these S-type granites in most of the Cordillera Real suggests that this segment of the Northern Andes has been affected by a larger collisional event. In the area around Sigüig/Principal to the north (see previous reports of traverses carried out by the Project), the western limit of both the Loja division and the Tres Lagunas unit is defined by a broader tectonic zone, called the Baños front (Aspden et al., 1987). The presence of the Tres Lagunas unit in the southern part of the Cordillera Real means that we are now able to follow the continuation of the Baños front in this area, where it is considered to be approximately equivalent to the Las Aradas fault.

Secondly, the Tres Lagunas unit has potential economic interest; in particular, most of the world's supply of tin (and to a lesser extent tungsten) is derived from "S-type" granites (for example, Malaysia, Indonesia, Thailand). Although it is premature to speak in terms of a major Sn/W belt, it is interesting to note that this is the only metal occurrence previously known in Ecuador (this is the Peggy Mine, Sigsig; and west of Saraguro) that is genetically related to the Tres Lagunas unit. Similarly, tourmalinized greisens exist east of Gima (see Annual Report of the Cordillera Real Project, 1988), the granites are tourmalinized, and there are also tourmaline pegmatitic blocks, which were observed in different plutons of the Tres Lagunas unit in the area of the Malacatos basin (see Map No. 3). Detailed work is required to determine the economic potential of the Tres Lagunas unit; however, such work should be carried out in the first place by INEMIN to gain access to what could be an important strategic resource.

2.6 Valladolid-Porvenir

To the east of Valladolid, on the road leading to Porvenir, an important section across the eastern margin of the Sabanilla basement is exposed, which in this area consists of biotitic gneisses with or without muscovite, generally with moderate to steep dips, and amphibole greisens with or without biotite, as indicated by Map No. 4. The margins of this complex correspond to well-defined lineaments in satellite imagery, and in this sector, it can be seen that towards the contact, the older gneiss basements have relatively gentle westward dips (approximately 30° to 35°) and that they have been thrust over a dominant lower-grade metasedimentary unit to the east. Minor amounts of younger (Cenozoic?) volcanics containing blocks of recrystallized limestone several meters high are present along the contact to the east.

The exposures along the road are very poor, but evidence from float blocks suggests that, to the east, the lithologies consist mainly of low-grade metasediments, which include not only quartzites and phyllites but also significant marble horizons. These latter rock types are spectacularly well-developed west of Porvenir, where they form prominent ridges with typical karstic features.

Furthermore, to the west, where the road crosses the Numbala River, outcrops of massive sedimentary breccias containing occasional thin phyllite interbeds have been observed.

An initial examination (hand samples) of these breccias suggests the presence of low-grade metamorphic clasts of semipelitic composition, and therefore provides data on the existence of an older, low-grade metamorphic basement.



Towards Porvenir, outcrops of biotitic quartz monzonite (?), with or without hornblende, have been studied. The contacts between this pluton and the metasediments to the west were not observed, but the pluton is considered to intrude subsequently. It is common to find float blocks, although silicified, in the streams along the road as one approach its margins.

Regionally, the “Porvenir” pluton is thought to represent the northern extension of the Río Mayo batholith. Useful samples for geochronological study were collected to test this hypothesis.

2.6.1 Economic Geology

2.6.1a Non-metallic: the abundant amount of marbles present could have commercial interest. Sampling could be carried out to determine their utility, for example, in cement manufacturing.

2.6.1b Metallic: residents pan for gold upstream in El Porvenir, but these areas were not visited.

Minor amounts of galena were observed in the marbles that occur immediately east of Sabanilla.

2.6.2 Basement complex

Regional considerations: structurally, the sequence of metasediments found to the east of the Sabanilla basement complex is considered to belong to the Oriente. The exposure level does not allow us to precisely subdivide these rocks at this time; therefore, they have been given an informal name and, in the future, will be referred to as the “older metamorphic rocks of the Eastern belt” (see Annual Report of the Cordillera Real Project, 1988).

As indicated before, it is thought that the rocks are intruded by the northern extension of the Río Mayo batholith and therefore they are considered to be of pre-Triassic age. It should be noted that on the published geological sheet at 1:100000 scale (Las Aradas), these rocks are not differentiated from the higher-grade gneisses of the Sabanilla basement complex.

To the south, east of Zumba, low-grade semipelitic rocks and marbles are present in the Isimanchi River (see Map No. 6). These rocks are tentatively assigned to the older metamorphic division of the Eastern belt.

2.7 Chito-La Cruz

Gold workings have existed for a long time SE of Zumba, and currently, detailed geochemical prospecting is being carried out under an agreement between Cyprus Minerals and Sacha Curi in part of this area. In response to an invitation made to observe this operation, work was carried out for a few days in the area north and east of Map No. 5. In addition, a rapid geological reconnaissance of the outcrops exposed along several roads east of Zumba was performed.

Details of the geological-structural observations carried out in the aforementioned areas are presented in the attached traverse map (see Map No. 5). The data south of La Cruz, between the Chinchipe River and the San Francisco River, are based on field work carried out by Ing. Napoleón Báez.

2.7.1 Geology

Geologically, the area between the Río Mayo to the west and the Río San Francisco to the east, which defines the border between Peru and Ecuador, is relatively simple. To the west, rocks of the Río Mayo batholith predominate, while to the east, volcanic rocks dominate.

Chemical analyses and thin-section information are not available at this time; therefore, the following description is based solely on the identification of hand specimens. The Río Mayo batholith is a composite pluton, but the main rock type found consists of a fine- to medium-grained biotite hornblende tonalite, which is well exposed in the Río Mayo. To the east of La Cruz, altered outcrops of medium- to coarse-grained granodiorite are present, but these have not been differentiated in the attached traverse maps.

The volcanics are considered to be mainly of andesitic composition. They are generally altered, but fresh outcrops are typically fine-grained and blue-green in colour, and include both porphyritic feldspar and porphyritic hornblende types. Silicified/feldspathized and pyritized volcanic and subvolcanic breccias are present in the Río Afiladeras. In other areas, quartz-feldspar zones with or without pyrite occur within the volcanics and are possibly related to low-temperature (epithermal) alteration.

In addition to volcanic and plutonic rocks, minor amounts of quartzite occur as float blocks in a small unnamed tributary on the left bank of the Quebrada Afiladeros. No outcrops were observed, but the quartzite is quite pure, white in colour, and shows no metamorphism. An examination of aerial photographs of the San Francisco area shows that immediately to the east in Peru, the volcanics are overlain with strong unconformity by probable sediments (see Map No. 5); while it is obviously not possible to visit these outcrops, quartzite float blocks have been reported from rivers flowing in these areas. The quartzite block found in the Quebrada Afiladeros is considered to represent the westward continuation of these quartzites, and with more detailed mapping, it is likely that smaller relicts will be located. The importance of these quartzites derives from the fact that in other parts of Ecuador, the Hollín Formation is characterized by similar lithologies and, if these rocks are indeed equivalent to the Hollín Formation, then this site not only establishes a minimum age for the volcanics of the Chito-La Cruz area, but also has important paleogeographic implications for the Oriente basin.



To the west of the Río Mayo and exposed along the road leading to La Chonta, there is a series of predominantly felsic and/or acidic subvolcanic rocks that are strongly altered, which commonly include porphyries. In the absence of age determinations, these rocks are tentatively considered younger than the Río Mayo batholith and could be related to marginal faults along the eastern margin of the Tertiary Zumba basin.

2.7.2 Age of the Río Mayo batholith and the Chito-La Cruz volcanics

At the moment, only a single age determination is available for the Río Mayo batholith. Samples collected to the north along the Palanda-Zumba road defined a 5-point isochron and yielded an age of 144 ± 35 Ma (Rundle, 1986). The wide error in this dating is due to the poor diffusion of Rb-Sr and therefore subsequent studies will be necessary to confirm these data.

The relationship between the Río Mayo batholith and the volcanics occurring to the west is unknown, but they are tentatively considered as belonging to the same volcanic-plutonic cycle. Samples from both the Río Mayo batholith and the volcanics were collected for age determination, and it is expected that these samples can resolve the problems.

2.7.3 Economic Geology

2.7.3a Gold: alluvial gold is widely distributed throughout the area and is commonly worked by the residents. Panned samples are typically fine-grained and pale, probably due to a high silver content.

Although it is not possible at this time to say if all the alluvial gold derives from a single “source”, it seems that many of the smaller streams, those flowing exclusively from the volcanics, contain gold. Currently, significant zones of low-temperature alteration have been located within the volcanics, and these contain both free gold and/or auriferous pyrite.

2.8 Area east of Zumba

Immediately to the east of Zumba, two small outcrops of serpentinite and related ultramafic rocks occur along the main road leading to Isimanchi. Towards the east, strongly deformed low-grade semipelites are present, and several marble blocks were observed along the road that continues toward the eastern flank of the Isimanchi River (see Map No. 5).

The exposures along the two roads leading east of Zumba toward the Zumba Yacu River and the Río Mayo are strongly altered, but they appear to consist largely of felsic volcanic/subvolcanic rocks that are possibly related to the Tertiary Zumba basin.



The age of the serpentinites is not known, but both outcrops are located along a strong photogeological lineament with a N-S direction. They are tentatively assigned a Tertiary age, but it is equally possible that they predate the formation of the Zumba basin.

The sequence of semipelites and marbles is probably older, as it appears intruded by the Río Mayo batholith.

2.8.1 Economic Geology

2.8.1a Non-metallic: although somewhat isolated, the marbles occurring south of Isimanchi could have commercial interest. Small-scale lime production, particularly for use in agriculture, might seem like an obvious possibility, given the local abundance of wood.

2.8.1b Metallic: minor amounts of hematite are present in quartz found in shear zones, associated with the main N-S trending fault east of Zumba.

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CORDILLERA REAL PROJECT

ATTACH. 5 geological-structural traverse maps



No. 3270

QUITO, JULY 01, 1987

TO : GERENTE TÉCNICO

FROM : INGS. RAMIRO BERMÚDEZ and FRANCISCO VITERI

SUBJECT : Commission Report (Dating Program)

SUMMARY:

This Report of the commissions carried out from May 4 to 14, 1987, and from May 25 to June 9, 1987, is summarized into a single report as they refer to the same subject.

The Dating Program planned for the months of May to June was one hundred percent completed; for this purpose, two commissions were required (north and south sectors of the country), during which around 221 samples were collected, mostly belonging to intrusive rocks (bodies). To ensure a better collection of "fresh" samples, 65% semexa dynamite (50 charges), electric blasting caps (49), electric cable, and a Pionjar 120 motor drill were used.

The obtained samples come from the following bodies: Pimampiro metapluton, Chingual and Sacha orthogneiss, Papallacta amphibolite, Abitagua and Azafrán granite, Zamora intrusive, San Lucas and Catamayo pluton, etc.

A detailed list of the samples collected (Annex 1A and 1B) is attached to each of the commissions; as well as a summary list of the rocks collected (Annex 2) for this program, which also includes the type of study to be carried out (London): isochrons, and age determinations using the K-Ar, Rb-Sr, and Sm-Nd (exceptionally) methods.

1. INTRODUCTION

1.3 Objective

To fulfil the Dating Program in the Cordillera Real planned for this quarter (II).

1.2 Assigned personnel

The valuable participation of the following personnel belonging to both the Project and the Institute was available, as follows:

Ing. Ramiro Bermúdez	INEMIN
Ing. Francisco Viteri	INEMIN
Dr. John Aspden	ODA/BGS
Sr. Bolívar Revelo	Assistant / INEMIN
Sr. Manuel Céleri	Driller/ INEMIN
Sr. Kerley Jurado	Driver/ INEMIN
Dr. C. C. Rundle	Geochronologist expert, belonging to the British Mission, in charge of conducting the studies to determine the ages.

Two Land Rover Jeeps, AT-0068 and AT-0056, were used for transport.

1.3 Location

Along the Cordillera Real of the country.

2. WORK METHODOLOGY

For each of the commissions, the following methodology was used:

- (a) Sample collection (predetermined sites in the field):
 - Sampling: project archive and for London (Chillogallo Lab).
 - Crushing (milling) of the rocks: fine powder and for separation.
- (b) Mineral separation:
 - Sieving of the grind: 16-30/30-60/60-120 meshes.
 - Sample washing (distilled water) and drying (oven).
 - Mineral separation by means of heavy liquids (bromoform, etc.).
 - Washing with acetone (heavy minerals: hb, bt, musc, etc.) and drying.
 - Magnetic mineral separation (hand magnet).
 - Weighing of the sample and placing it in its respective bag.

It is necessary to emphasize the efficient work carried out by the personnel of the Chillogallo laboratories: Srs. German Casanova, José Rodríguez (crushing and milling), and Sr. Guillermo Erazo (heavy mineral separation).



3. GEOLOGY

The rock collection for this program was taken from the various geotraverses executed during the first year by the Project in the Cordillera Real, as follows: Tulcán-La Bonita, Papallacta-Baeza, Baños-Puyo, Salcedo-Tena, Guamote-Huamboya, Laguna de Cubillín, Saraguro-Loja, Catamayo-Loja-Zamora, Loja-Zumba, Sigsig-Mina Peggy, and Gualaceo-Plan de Milagro-Limón.

The samples required for this study had to meet two requirements: first, to be as representative as possible of the various intrusive and metamorphic bodies, and second, to be as “fresh” as possible. The following bodies were visited:

- The Pimampiro metapluton: outcrops along the Monte Olivo road and in the Chuga sector; the rock is an orthogneiss with crystals of hornblende, biotite, and muscovite.
- Sacha Orthogneiss: outcrops along the Sta. Bárbara-El Playón road; the predominant rock is a biotitic orthogneiss. There are also blocks of biotitic paragneiss and granitoid hornblendic orthogneiss.
- Chingual Orthogneiss: it is the most prominent of the El Playón-La Bonita sector; at the SE contact, this orthogneiss belt contains biotite and hornblende for about 100 m.
- Papallacta Amphibolite: located on the Baeza road a few meters from the town; the rock is dark in colour with the presence of blue quartz, hornblende and biotite, epidote, and disseminated sulphides.
- Azafrán and Abitagua Intrusives: the Azafrán intrusive is found on the Baños-Puyo road; it is a medium to coarse-grained body containing quartz, epidote, and chlorite/biotite.

The Abitagua Granite outcrops in the Baños-Puyo and Baeza-Tena sections; samples belonging to this intrusive were collected from both sectors.

- “Magtayán” Intrusive (Laguna de Magtayán): this body is located in the Osogoche sector; samples were obtained from some large light grey blocks with large hornblende crystals with centimetre-scale veins of epidote (?).
- Samples of schists and gneiss were taken containing garnets both at the exit of the old tunnel (Baños-Puyo road) and about 50 to 80 m before the new bridge over the Pastaza River.
- Regarding the south of the country: first, sampling was carried out at the Peggy Mine; these consist of a silicified porphyry (?), with a content primarily of blue quartz.



- From the Gualaceo, Plan del Milagro, Limón section, samples were taken at the bridge for crossing the San Francisco River, corresponding to lavas from the Paute Group.
- On the Guadalupe-La Paz road, samples were taken to perform an isochron at the northwestern end of the Zamora Batholith; in this sector, the variety of intrusive rocks is significant, noting granodiorites with hornblende and biotite, felsite dikes, diorite, and tonalites.
- A new sampling of the Zamora Batholith was carried out on the road under construction leading from Zamora-Congüime-El Cóndor, that is to say, at the northeastern end of that batholith; in these sectors, the rock shows little variation regarding its mineralogical composition, consisting mainly of a tonalite with hornblende and biotite; samples of felsite dikes and a boulder in the Chinapintza Creek of a subvolcanic rock? (feldspathic porphyry) were also taken.
- Finally, to conclude the sampling of the Zamora Batholith, sampling was carried out in Pituca Creek and the Jambué River south of the Zamora canton, consisting of boulders several meters in diameter composed of hornblende biotite granites, microgranodiorite with green? hornblende.
- The Sabanilla gneiss-migmatitic complex was sampled on the Loja-Zamora road under construction; this complex showed variation both in its rock type and its structure. The main rocks identified and sampled are: gneissic breccia, quartzose gneiss, homogeneous migmatite with quartz and feldspar, leucocratic gneiss? with quartz, feldspar, and biotite.
- The Valladolid complex was sampled near the town of the same name; it is a pegmatite with quartz and muscovite, also containing biotite and feldspar; the size of the muscovites reaches up to 2 cm.
- The Río Mayo Batholith was sampled on the stabilized road leading from Palanda-Zumba; this intrusive consists of a tonalite with hornblende and biotite, with the mafic content varying in some cases; likewise, the presence of xenoliths containing small epidote veinlets was observed.
- Portachuela Pluton: the sampling of this pluton was carried out on the road under construction leading from Amaluza-Jimbura and Zumba (projected), a few kilometres from the border with Peru, and consists mainly at the southern end of subvolcanic rocks (porphyritic with biotite?), felsic granite, hornblende granodiorite, and a tonalite with hornblende phenocrysts of greenish coloration.



- The San Lucas pluton: this pluton, known by a good portion of geologists on the Loja-Saraguro road, was sampled both in outcrops and in boulders from the Las Juntas River; it consists mainly of a microgranite, aplite gneiss, a microtonalite/granodiorite possibly with biotite, a biotitic gneiss? finally a gneissic tonalite?
- Finally, the small pluton named Catamayo was sampled on the new road leading from Catamayo (La Toma) to Loja, more precisely at the Gavilanes ridge; it consists mainly of a slightly altered biotitic tonalite.

4. CONCLUSIONS AND RECOMMENDATIONS

The dating program was one hundred percent completed as planned (Execution Schedule).

The sample preparation work (221), carried out in the Chillogallo laboratories (INEMIN), was done efficiently, and the personnel who collaborated in it deserve recognition from the Project.

65% semexa dynamite (50 charges), electric blasting caps (49), and electric cable were purchased and used. Once accounted for, the respective return was made to the Institute's warehouse.

The samples sent to London will be analyzed for 12 isochrons, K-Ar, Rb-Sr, and Sm-Nd. The first results could be available by the end of this year; these are of great importance for the progress of the project, which is interested in determining the complex evolution of the Cordillera Real.

Ing. Ramiro Bermúdez A.

Ing. Francisco Viteri

CORDILLERA REAL PROJECT

ADJ. Annexes

CC. International Missions

